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DIRECT AND ALTERNATING CURRENT

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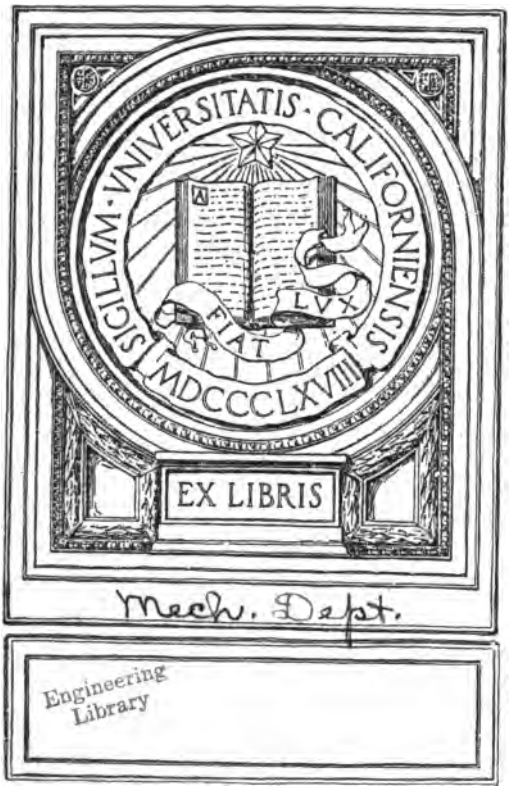

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LABORATORY MANUAL

Direct and Alternating Current

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LABORATORY MANUAL

DIRECT AND ALTERNATING CURRENT

Prepared to accompany Timbie's Elements of Electricity

By

CLARENCE E. CLEWELL

Sheffield Scientific School of Yale University

SECOND EDITION

UNIV. OF CALIFORNIA

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PREFACE

This book of laboratory directions is designed for the use of students in courses other than that of Electrical Engineering, who take a brief amount of work in the fundamental principles of electricity.

The object of the laboratory work in such cases is to aid in the understanding of the theoretical and practical items given in the recitation and lecture room. It is the purpose, therefore, to eliminate in as far as possible all features in the actual work of the laboratory which would tend to lessen or detract from concentration upon the underlying principles involved in the experiment in hand.

To facilitate the work, each experiment is prefaced where possible by an assignment of articles in the text book which bear directly or indirectly on the experiment in question. Further, in a part of the experiments, diagrams of the electrical connections will be found, together with simple forms which may be followed in the recording of observations. These forms are somewhat more complete in the first than in the advanced experiments in order to serve at the outset as a guide in the preparation of the data sheets. In the latter experiments this general scheme of ruling up the data sheet is to be followed by each group of men in the preparation of data sheets before the laboratory exercise.

After teaching with a text book which was too advanced for the students and a laboratory manual which was not suited to the text book, the students nor the equipment, it was thought best to write a Manual which should be adapted to the specific requirements of the coming year. The difficulties encountered by the student have been observed and the aim of the Manual is to present the subject from his standpoint. The emphasis placed on such practical items as constant potential supply mains in the wiring diagrams, and the practical points connected with direct and alternating current generators and motors and power trans-

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mission in the text, are intended to familiarize the student with the principles underlying the operation of standard apparatus which he may encounter after graduation.

Appreciation for many suggestions and helpful advice in the make-up of this book is due Professor Chas. F. Scott, Sheffield Scientific School of Yale University.

CLARENCE E. CLEWELL.

NEW HAVEN, CONN.,
July, 1913.

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LABORATORY MANUAL

INTRODUCTION TO THE LABORATORY WORK.

1. General Hints.—While the laboratory work is intended primarily as an aid to a clear understanding of the text book and lecture work, to be successful, it must be performed in a systematic manner, and with due care in handling electric circuits, instruments and machinery.

The electric current is somewhat intangible and when making connections and carrying out tests, the only way to conduct the work intelligently is to form at the outset definite ideas of the laws which govern the flow of current in the circuit involved.

A most important item to observe is the distinction between electric pressure (electromotive force) expressed in *volts,* and electric current expressed in *amperes,* and quantitative ideas should be gained early in the work regarding the usual values of these units. The most common value of pressure in commercial lighting is approximately 110 volts. The normal voltage is different in different plants; it may be 108, or 110, or 115, etc. In each case the aim is to maintain the normal value at all times. The general term "110 volts" is used to mean a constant potential circuit of the 110-volt class. An ordinary carbon filament incandescent lamp consumes one-half an ampere with a pressure of 110 volts across its terminals. The principal circuits used in the laboratory tests are 110 and 220 volts. Electric railway circuits are ordinarily 550 volts, and five 110-volt lamps are connected in series in the cars for lighting.

In connecting up a set of apparatus and the instruments for a test, some idea should be had of what each component part of the circuit stands for in its relation to the whole, as well as a fairly definite idea of what will happen when the main switch is closed. As a safeguard, the Instructor should always be asked to check

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over the connections before power is applied through the closing of the main switch.

As to the connections themselves, a switch, together with a fuse in each side of the line, should be installed. The switch should be closed and opened quickly at the start to see if all is correct, and after the switch has been closed and the work started, each piece of apparatus should be watched closely for the first few minutes to note if any part of the circuit is being overheated. Should any trouble exist, open the switch at once and trace the connections to find the error. A heavy current will flow through a low resistance at 110 or 220 volts, and hence, in using apparatus having low resistance an adequate additional resistance must always be placed in the circuit before closing the switch.

2. Material Required for the Work.—Each man is to have the following items:

(a) Paper for use in recording data with carbon paper for duplicating the data sheets.

(b) A pad of ruled loose leaf note paper on which the report is to be written, together with suitable report covers.

(c) A pad of cross section paper the same size as the loose leaf paper for curve plotting.

It is suggested that students provide themselves with a pair of wireman's pliers and a screw driver.

3. Instruments.—Electrical measuring instruments are delicate and expensive and they should be handled with the same care that one would use in the handling of a high grade watch or equivalent piece of jewelled apparatus. Damage to instruments through carelessness is chargeable to the students involved.

Ammeters.—An ammeter is a low resistance instrument and is intended for the measurement of the electric current which flows through its coil. The important item is to avoid sending through the ammeter a current which is larger than it is intended to carry. A safeguard is a short circuiting switch as shown in Fig. 1. When this switch is closed the current flows through the switch and the ammeter is thus protected. When the observations are to be made, the switch is opened and the current flows through the instrument. This precaution, while not always necessary, is sufficiently important to make it desirable in the early experiments.

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Millivoltmeters and Shunts.—A resistance of known value R may be connected in the circuit (the shunt in Fig. 1), and a low reading voltmeter known as the millivoltmeter ("thousandths of a volt" meter) may be connected across its terminals to determine the current flowing through the resistance R. If e is the reading on the millivoltmeter in millivolts (thousandths of a volt), the current is then equal to

$$\frac{e}{1000} \div R \text{ or } \frac{E\,(\text{volts})}{R}$$

These instruments may be calibrated to read amperes directly, or what is more common in the laboratory, the shunt is stamped

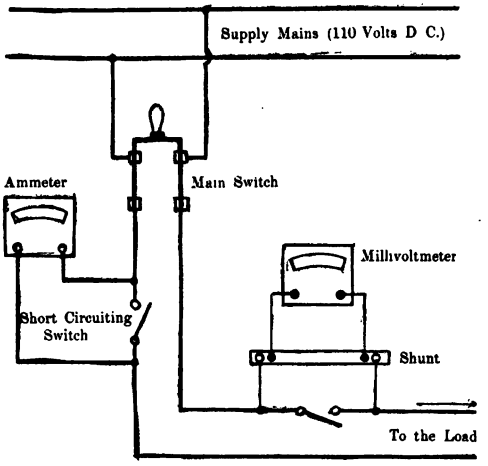

Fig. 1.—Two types of instrument for measuring current: (a) ammeter, carrying the full current; (b) shunt with millivoltmeter for measuring the voltage drop in the shunt. Note the short circuiting switch for the protection of the instrument in each case.

with the current which flows through the circuit when the millivoltmeter to which it is connected indicates its full scale deflection. Thus a millivoltmeter whose full scale deflection is 100, when used with a shunt stamped 10, indicates 10 amperes when the millivoltmeter registers its full deflection, that is, each scale division indicates one-tenth of an ampere. All shunts in the laboratory are numbered according to the instrument with which they are to be used, and in all cases the number on the shunt and on the instrument must correspond.

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Voltmeters.—A voltmeter is a high resistance instrument and, hence, is actuated by a relatively small current flowing through its coil. The voltmeter is intended for use across a circuit and measures the pressure E effective between its terminals. If the resistance of the voltmeter is R, and it is connected across 110-volt mains, the current flowing through the instrument is $110/R$. Thus the voltmeter is, in reality, a current-measuring instrument on a small scale, but its divisions are calibrated in volts and the current is usually a very small fraction of an ampere or a negligible quantity in most of the practical experiments. The range of a voltmeter may be increased by the use of an external supplemental resistance termed a multiplying coil, although in many of the simpler tests this is unnecessary, since instruments of a suitable range are available.

4. Use of Instruments.—Always keep an instrument away from stray magnetic fields like those in the neighborhood of some electromagnets and some generators and motors. Outside magnetism may affect the accuracy of an instrument very appreciably.

Where the wires from an instrument cross the floor and there is danger of it being pulled off the table, the wires should be anchored to a table leg or should pass through holes in the table provided for this purpose.

No instrument should be used where the reading to be taken is less than one-third of its full scale deflection, since the accuracy of an instrument is greater for higher than for lower readings.

Observe and record the zero deflection of each instrument before connecting it into the circuit, also record the correction constant of each instrument on the data sheet. If this constant is appreciable, each observation should be duly corrected. Note on the data sheet the number of each instrument used somewhat as follows:

Weston Voltmeter No. 65.

Zero deflection, 0.5 volt; Correction constant, ± 0.97.

5. Rheostats.—A suitable rheostat or adjustable resistance should be employed in most cases, both as a protection for circuits of low resistance and to afford the required adjustments of the current throughout the experiment. Always select a rheostat

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that will carry the required current without overheating and that will give the necessary variations of resistance.

So-called field rheostats designed for use in series with the shunt field windings of generators, are adapted to low current values, and must not be used where larger currents are involved. Look on the rheostat for its current rating.

A bank of incandescent lamps connected in parallel may be used as a rheostat. A lamp bank is a safe device to use for this purpose because the resistance cannot be reduced to zero. Note that when one lamp is turned on the resistance is twice as great as when two are on. In other words, the more the lamps turned on the less the resistance. Each 16 candle-power carbon lamp when burning has a resistance of about 220 ohms and carries one-half an ampere at 110 volts.

Other types of rheostats for special purposes are usually available in the instrument rooms.

6. Circuit Breakers and Fuses.—When a circuit breaker opens, always open the main switch before closing the breaker, then close the switch. If trouble is still on the line, the breaker is apt to open when the switch is closed.

If a fuse blows, open the main switch before replacing the fuse, and after the new fuse has been installed close the main switch. See that the fuse is of the proper size for the circuit it is to protect.

7. Constant and Variable Factors in the Experimental Work.—In many of the experiments, observations are made of the changes which take place in one or more factors when certain conditions are maintained constant and certain other factors are varied according to some prescribed method. This gives rise to three classes of observation items, namely, constants, independent variables and dependent variables.

For example, in Experiment 1, under item 1, *Order of Work,* with a given size and kind of wire and a constant current flowing, the lengths of the wire are to be varied and the changes in the volts drop for these different lengths are to be observed. Here the constants are the size and kind of wire and the current; the independent variable, that which is changed directly by the operator, is the length of the wire; and the dependent variable is the volts drop.

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In each experiment, the student is to indicate on the data sheet, preferably at the top of the various columns, to which of these classes of observation items the data belongs.

8. Suggestions for the Work in the Laboratory.—The foreman of each group of men is to prepare a ruled and labelled data sheet on the paper for that purpose before the work of taking observations is begun. There is to be one data sheet for each man in the group and one extra copy is to be made for placing on file with the Instructor.

To secure instruments before beginning the work, fill out a requisition card with complete designation of each instrument desired.

Before disconnecting the apparatus, have the data sheets approved by the Instructor so that if any observations are missing, they may be taken without the trouble of re-connecting the apparatus.

At the end of the experiment, return all instruments to the supply room, disconnect all wires and arrange the apparatus in the same condition in which it was found.

The usual order of the work in a given laboratory period may be summarized as follows:

1. Recitation on the assigned articles in the text book and on the *Theory* in the Manual.
2. General inspection of the apparatus to be used.
3. Data sheets ruled up and the columns of same labelled by the foreman of the group.
4. Requisition card filled out and instruments secured from the supply room.
5. Connections made, and inspected by the Instructor before power is applied to the apparatus.
6. Observations taken for securing the required data.
7. Data sheets approved and stamped by the Instructor before the connections are taken apart.
8. Connections taken down, instruments returned to supply room and apparatus put in order.
9. Carbon copy of data placed on file with the Instructor, and assignment of experiment for the following exercise ascertained.

9. Written Report.—The written Report is to consist (a) of the original data sheet; (b) a diagram of the connections em-

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ployed in each item of the given experiment showing the instruments on the drawing labelled with their respective laboratory numbers; (c) answers and calculations based on the heading *Written Report* at the end of each experiment in the following directions. These report pages are to be bound by a brass clip into the laboratory cover, and on this cover the blanks are to be duly filled in with the name of the student, number of the experiment, and so on.

The following rules will be observed in connection with the written reports:

(a) The written report on a given experiment is to be handed in one week after the performance of that experiment, that is, where there is one laboratory exercise each week, the written report is to be handed in at the laboratory exercise next following that on which the experiment was performed.

(b) An extension of time will be granted, provided a written valid excuse is presented on the form provided for this purpose, on the due date of the report, approved by the Instructor, and attached to the data sheet in the report when the latter is handed in.

(c) Reports handed in after the expiration of two weeks from the date on which the experiment was performed (except in case of illness) will be given reduced credit.

NOTE: The actual work on the written reports of the various experiments has been reduced to a minimum consistent with an understanding of what was done in making the observations. The advantageous time to make up such a brief summary of the work performed in a laboratory exercise is within a week after the actual performance of the work. Hence the preceding requirement (*a*) stating that the report is due one week from the laboratory exercise involved.

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Experiments 1 to 20, inclusive, constitute the Direct Current portion of the Manual.

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DIRECT CURRENT

EXPERIMENT 1.

Ohm's Law.

See articles 48, 49, 50, 52, 53, 73 and 81 in the text book (Timbie's *Elements of Electricity*).

The purpose of this experiment is to verify the relations of pressure or electromotive force (E) in volts, current (I) in amperes, and resistance (R) in ohms in a circuit as expressed by Ohm's law.

Theory.—Nearly all electrical problems involve a knowledge of Ohm's law. This law may be expressed by the following equation:

$$\text{Current} = \frac{\text{Pressure}}{\text{Resistance}}; \text{ or Amperes} = \frac{\text{Volts}}{\text{Ohms}}; \text{ or } I = \frac{E}{R}$$

obviously this expression may be written in the following forms:

$$E = RI \text{ and } R = \frac{E}{I}$$

In the use of this law, it is very important to consider I, E and R in the particular portion of the circuit involved, and further, the law applies only to that portion of E which is used in overcoming resistance. The voltage E measured between the ends of a simple wire or across the terminals of a motor armature when stationary may be substituted in the formula for Ohm's law with the corresponding current, for the calculation of the resistance R, because all of E is used in overcoming resistance in these cases. In delivering current to an electric motor in motion, however, a portion only of the pressure (or voltage E) at the terminals of the motor armature is used in overcoming resistance in the armature windings, the remainder of the pressure going to overcome the voltage generated in the armature and thus being available as

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useful pressure in the rotation of the machine. In this latter case, the voltage recorded by a voltmeter at the terminals of the armature cannot be used in the formula for Ohm's law because a portion only of this voltage is used in overcoming resistance.

When the resistance of a simple wire is determined by measuring E and I and substituting in Ohm's law, the method is known as the voltmeter-ammeter method of measuring resistance.

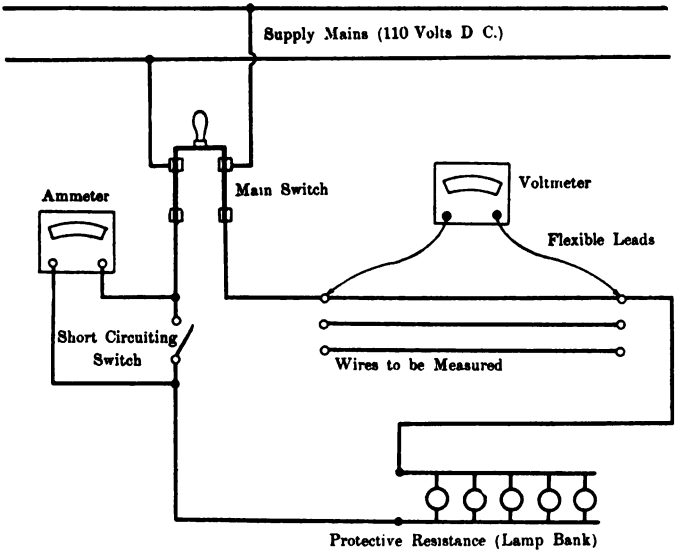

Fig. 2.—Apparatus and connections for measuring the resistance of a wire by the voltmeter-ammeter method.

Current Supply.—110 volts Direct Current.

Apparatus Required.—(1) Lengths of various sizes and kinds of wire; (2) protective resistance; (3) yard stick; (4) incandescent lamps arranged for series or parallel connection; (5) fuses; (6) suitable voltmeter with flexible leads; and (7) an ammeter.

Order of Work.—Make a diagram of the exact connections employed in each of the following items, labelling each instrument on the drawing with its laboratory number.

1. Place a suitable protective resistance in series with the ammeter and the wire to be tested as shown in Fig. 2. With a

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given constant current flowing through the wire as indicated by the ammeter, observe the volts drop across 1/3, 2/3 and the entire length respectively of the wire and observe the supply voltage. Record these observations as in Form 1.

No.	Supply Voltage	Kind of Wire	Size of Wire	Length of Wire in Feet	Amperes	Volts Drop
1						
2						
3						
4						

Form 1.

2. With the voltmeter across the entire length of the wire used in item 1, observe the volts drop for three different values of current and record as in Form 1.

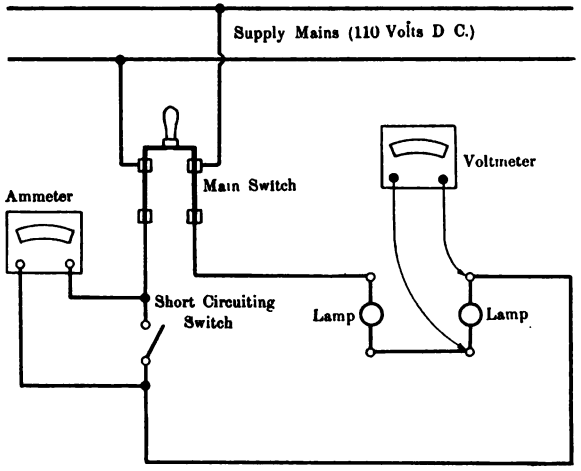

Fig. 3.—Wiring diagram for a study of the voltage and current relations in a series circuit, made up, in this case, of two incandescent lamps connected in series.

3. Repeat items 1 and 2 for the second and third samples of wire.

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4. With two lamps in series with the ammeter as in Fig. 3, observe the current and volts drop across each lamp and the supply voltage, using Form 2.

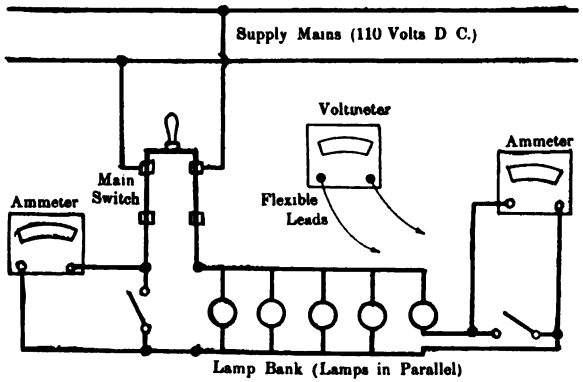

Fig. 4.—Diagram for a study of the voltage and current relations in a parallel circuit, made up, in this case, of several incandescent lamps in parallel.

5. With the lamps connected in parallel, all the lamps turned off except one, and an ammeter in series with this one lamp as shown in Fig. 4, observe the current in and the volts drop across this lamp. With the same lamp turned on, repeat for a second lamp, observing the current in the second lamp by the difference in the readings of the two ammeters. Use Form 2.

No.	Circuit Involved	Supply Amperes	Amperes in One Lamp	Supply Voltage	Volts Across One Lamp
1					
2					
3					

Form 2.

Written Report.—The written report is to consist of the original data, and a diagram of connections as specified in Article 9 of the Introduction, together with answers to the following questions.

1. On what does the resistance of a wire depend?

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2. On what does the voltage-drop in a wire depend?

3. Explain briefly the results under item 1, *Order of Work,* and calculate the resistance in Ohms for each of the three observations.

4. Explain briefly the results under item 2, *Order of Work,* and calculate the resistance in Ohms for each of the three observations.

5. Same for items 3 and 4, *Order of Work.*

6. From the observations taken, what effect has the size and kind of wire on the resistance?

7. What distinguishes the relations of voltage and current in the component parts of series and parallel circuits to the supply voltage and current?

EXPERIMENT 2.

Measurement of Armature and of Field Resistance.

See Articles 75, 81 and 115 in the text book (Timbie's *Elements of Electricity*).

The purpose of this experiment is to measure the resistance of the armature and of the shunt and series field windings of a generator by the voltmeter-ammeter method.

That portion of a circuit carrying relatively high current usually has a low resistance in order to reduce the losses in the circuit. Hence, an armature and a series field of a generator, through which the main part of the generated current flows, have low resistance windings, while the shunt field winding, through which a relatively small current flows, has a high resistance winding.

Current Supply.—110 volts Direct Current.

Apparatus Required.—(1) A compound generator; (2) protective resistance (lamp bank), and (3) a suitable ammeter for the armature and series field winding; (4) an adjustable resistance (field rheostat), and (5) a suitable ammeter for the shunt winding; and (6) suitable voltmeters with flexible leads for the three sets of observations.

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Order of Work.—Make a diagram of the exact connections employed in each of the following items, labelling each instrument on the drawing with its laboratory number.

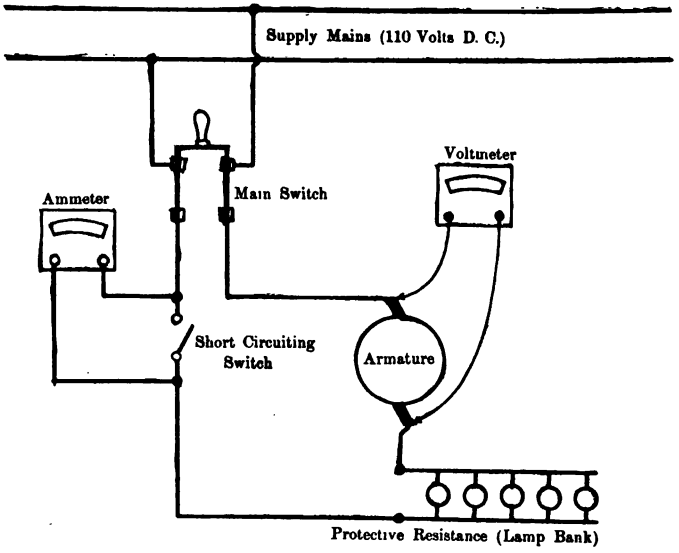

Fig. 5.—Measurement of the resistance of an armature when stationary. In the case here shown, the voltmeter indicates the volts drop between the armature terminals.

1. With a suitable protective resistance (lamp bank) in series with the armature (which is at rest), and the ammeter as shown in Fig. 5, observe the volts drop across the armature of the machine for say 25, 50 and 75 per cent. of full load current (see name

No.	Percent. of Full Rated Current	Amperes	Volts Drop	Resistance in Ohms (To be Calculated Later)
1				
2				
3				

Form 3.

plate on machine for normal current). Allow a brief interval between each of these observations to note the effect of temperature rise on resistance. Use Form 3.

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2. Repeat with the series field winding in place of the armature.

3. With an adjustable resistance (field rheostat) in series with the shunt field winding and the ammeter, observe the volts drop across the field terminals for the normal field current (when the normal machine voltage is impressed on the field) and for ten and twenty per cent. below normal value. The shunt field current is so small that a smaller ammeter will probably be required than in items 1 and 2.

Written Report.—1. What is the resistance of the armature for each of the three values of current? What is the average?

2. Same for the series field winding?

3. Does the resistance increase for the higher values of current in 1 and 2, and if so, why?

4. What is the resistance of the shunt field winding for each of the three values of current? What is the average?

5. Why is Ohm's law applicable to the finding of the resistance in each of these three cases?

6. Would Ohm's law apply if the armature in item 1 were in motion? Explain briefly.

EXPERIMENT 3.

Voltage and Power Losses in Transmission.

See Articles 45, 46, 47, 61, 62 and 69 in the text book (Timbie's *Elements of Electricity*).

The purpose of this experiment is to gain a working knowledge of the calculation of volts drop and power loss in the transmission of electric power from one place to another.

Theory.—In the transmission of electric power (EI) over longer or shorter distances, the current I determines the loss in voltage and the loss of power for a given size of transmission wire. Thus, if the resistance R of the two wires out and back be known, the product RI indicates the volts drop in the line (out and back), and the product RI^2 indicates the power loss (watts) in transmission. In the simple apparatus shown in Fig. 6 (see Fig. 97, Timbie), the two wires leading from the supply switch

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to the lamps serve on a small scale as transmission wires, conducting the electric current from the supply switch to the lamps.

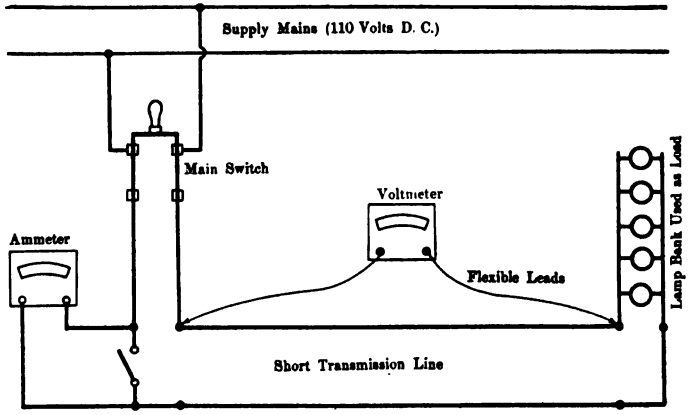

Fig. 6.—Measurement of the voltage and power losses in a short transmission line. The voltmeter, as here shown, indicates the volts drop in one side of the line only.

Current Supply.—110 volts Direct Current.

Apparatus Required.—(1) Long wires across the room arranged as in Fig. 6; (2) a low and (3) a high reading voltmeter with flexible leads; and (4) an ammeter.

No.	No. of Lamps Used	Supply Voltage	Lamp Terminal Voltage	Amperes	Volts Drop			These Line Calculations to be Made Later		
					One Side of Line	Other Side of Line	Both Sides of Line	Resistance in Ohms	Volts Drop = RI	Watts Loss = RI²
1										
2										
3										

Form 4.

Order of Work.—Make a diagram of the exact connections employed in each of the following items, labelling each instrument on the drawing with its laboratory number.

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1. Measure the current in each wire separately, which connect the lamps to the supply switch, also the volts drop in these two wires (all the lamps being turned on), from which the resistance R of the wires may be calculated by Ohm's law. Use Form 4.

2. Measure the supply voltage and the voltage at the lamp terminals for a constant value of current (all the lamps turned on), recording these observations in Form 4.

3. Repeat 1 and 2 when half of the lamps are turned off, using Form 4.

Written Report.—1. Calculate the resistance R for each of the wires in 1, *Order of Work,* and calculate the total RI (volts) drop and the total RI^2 (watts) loss in the two line wires.

2. Find the RI drop in the line wires for 2, *Order of Work,* by subtracting the voltage at the lamp terminals from the supply voltage.

3. Calculate the resistance R for each of the wires in 3, *Order of Work,* and calculate the total RI (volts) drop and the total RI^2 (watts) loss in the line wires for half the lamps in operation.

4. How does the RI drop in 1 and in 2 compare?

5. How does the RI drop and the RI^2 loss in 1 and in 3 compare? Explain briefly.

EXPERIMENT 4.

Study of Measuring Instruments.

See Articles 57, 58, 59, 60, 61, 62, 63 and 64 in the text book (Timbie's *Elements of Electricity*), also Articles 3 and 4 in the introduction to the Manual.

The purpose of this experiment is to gain an understanding, both as regards construction and operation, of the features of electrical instruments for the measurement of current, voltage and power.

Theory.—The underlying principle on which a majority of instruments is based, is the mechanical force produced on a wire carrying current when the wire is placed in a magnetic field. This mechanical force is directly proportional to the current for

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a given value of the magnetic field and for a given length of wire. Hence, by the introduction of a balancing hair spring, the motion of the pivoted wire and, hence, that of the attached needle or pointer is proportional to the current strength.

In the ammeter the scale of the instrument is calibrated in amperes; in the voltmeter, the needle is actuated by the current through the movable coil, but the scale is calibrated in volts (this is possible since $E=I/R$ where R is the constant resistance of the instrument).

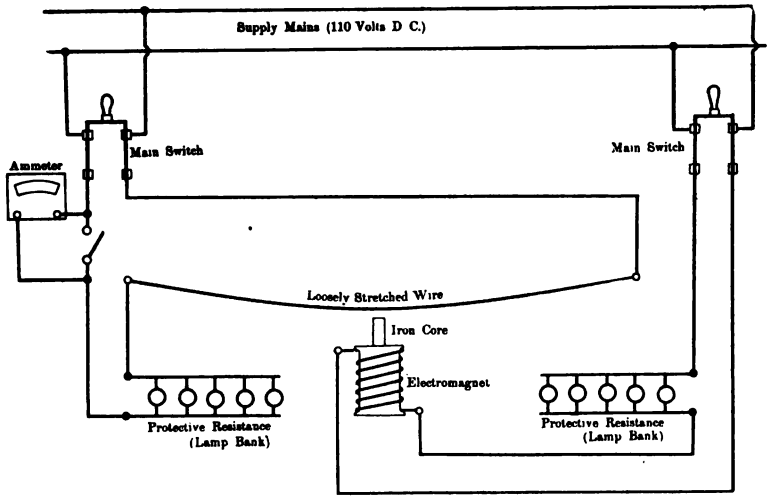

Fig. 7.—Diagram for observing the mechanical force on an electric wire when placed in a magnetic field.

In the wattmeter the magnetic component of the mechanical force is proportional to the main current since the magnetism may be considered as produced by the main current through a stationary coil, while the movable coil carries a current value which is proportional to the voltage E across the terminals of the instrument, therefore, the deflection of the needle is proportional to the product EI. Hence, the wattmeter is a combined ammeter and voltmeter.

In the watt-hour meter, the principle is that of a small motor in which the force and the number of revolutions per second is proportional to EI, and the total number of revolutions in a given time t and, hence, the displacement of the pointers on the dials

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is proportional to the product *EIt*. The watt-hour meter is used in residence electric lighting work for recording the number of watt-hours consumed per month.

Current Supply.—110 volts Direct Current.

Apparatus Required.—(1) A length of small sized wire; (2) a protective resistance (lamp bank); (3) a strong electromagnet; (4) a Siemens Electrodynamometer; (5) a board on which are mounted the parts of a Weston instrument; (6) a Weston ammeter (10 amperes range); (7) a Weston voltmeter (150 volts range); (8) a wattmeter (5 amperes, 150 volts range); and (9) a watt-hour meter.

Order of Work.—Make a diagram of the exact connections employed in each of the following items which make use of the electric current, labelling each instrument on the drawing with its laboratory number.

1. Connect the length of small sized loosely stretched wire in series with an ammeter and a protective resistance (lamp bank), also connect the electromagnet in series with a lamp bank and a second supply switch as shown in Fig. 7. With the current of about five lamps flowing through the loose wire, quickly close the supply switch of the magnet. Note the mechanical force on the wire. Open and close the switch of the electromagnet a number of times in succession. Repeat with the current of one lamp and of ten lamps flowing through the loose wire.

2. Connect the Siemens Electrodynamometer in series with a lamp bank to the line and note the action of the movable coil when a current flows through the instrument; reverse the current and note the direction of the force as compared to the direction in the preceding case. (Caution: do not exceed the current rating of the instrument.) Note carefully what produces the mechanical force on the movable coil.

3. On the board containing the parts of a Weston instrument note and make a simple sketch of the magnet and of the movable coil. Look for these parts through the glass in the cover of one of the Weston instruments.

4. Connect a lamp bank and the ammeter, voltmeter, wattmeter and watt-hour meter as shown in Fig. 8. Turn on a portion of the lamps and observe the reading of the watt-hour meter

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before and say 15 minutes after turning on the lamps. Observe and record the ammeter, voltmeter and wattmeter readings several times during this 15 minute interval. Use Form 5.

Before disconnecting this apparatus open the supply switch, reverse the terminals of the ammeter and close the switch momentarily. Note the effect on the direction of force as shown by the movement of the needle.

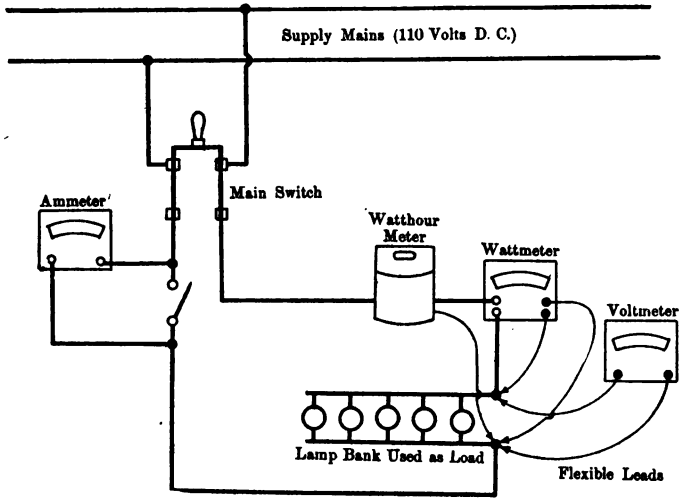

Fig. 8.—Measurement of the power supplied to a bank of lamps. The flexible lead from the watthour meter is one voltage connection, the other is made in the instrument to the wire carrying the main current.

Written Report.—1. What effect was produced by the larger as compared with the smaller current values through the loosely stretched wire on the mechanical force in item 1, *Order of Work*? What was the function of the electromagnet in this particular test?

2. What produces the mechanical force in the Siemens Electrodynamometer? What effect was produced on the direction of this mechanical force by reversing the current through the instrument? Why?

3. From the results obtained under item 4, *Order of Work*, calculate the watt-hours from the voltmeter and ammeter readings, and from the wattmeter readings and compare each of these

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results with the number of watt-hours recorded by the watt-hour meter.

4. If the commercial rate for electric power in residence lighting is 9 cents per 1000 watt-hours (9 cents per kilowatt-hour), then, in a residence containing twenty 25-watt tungsten lamps, how many hours can all the lamps be turned on per night for a month of 30 days to make the bill equal $3.60 for the month?

5. What effect was produced on the direction of throw of the ammeter needle in item 4, *Order of Work,* when the connections were reversed? Compare this result with that of the direction

No	Time	Amperes	Volts	Watts	Watthour Meter Readings	Watthours for the Interval (To be Calculated Later)		
						From Watthour Meter Readings	From Voltmeter Ammeter Readings	From Wattmeter Readings
1								
2								
3								

Form 5.

of force on the Electrodynamometer when the current was reversed in its coils? Explain the difference briefly.

EXPERIMENT 5.

Study of Fuses and Circuit Breakers.

See Article 36 in the text book (Timbie's *Elements of Electricity*), also Article 6 in the Introduction to the Manual.

The purpose of this experiment is to gain familiarity with the make-up of various types of fuses, the elements of fuse blocks, and the construction and operation of circuit breakers.

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Theory.—The simple fuse is an alloy with a relatively low melting point. A fuse is inserted in a circuit, usually one on each side of the line, as a protection against overloads and short circuits, which might otherwise injure the wires or appliances in the circuit. Fuses may roughly be classified either as open or enclosed. In the enclosed type, commonly known as the cartridge fuse, the fuse wire is surrounded with a fire-proof covering which prevents the scattering of small particles of hot fuse metal in case of a blow-out.

The distance between the terminals on standard fuses depends on the voltage, that is, with higher voltages the fuse terminals are made farther apart so as to reduce the likelihood of the current arcing across the terminals when the fuse is blown. It is obviously very important in fusing up a circuit, to use a fuse so rated as to protect the circuit against current values in excess of the permissable limiting current for the circuit. Thus, if the maximum allowable current is 10 amperes, the rating of the fuse should not exceed this current value. Fuses are usually so rated as to allow a small margin above the rating before the fuse actually blows. If the circuit is opened by the blowing of a fuse, an inspection will often show whether the blow-out has been due to a simple overloading of the circuit or to a short circuit. If a slight overload, the fuse is melted away without the appearance of burns on the porcelain fuse block. If a short circuit, the charred or burned appearance of the fuse block generally indicates the fact. The inspection here mentioned refers mainly to the open fuse.

The circuit breaker is an electromagnetic device which mechanically opens the circuit when the current exceeds the value for which it is adjusted or set to open. The continual breaking of the circuit between metal surfaces would soon cause excessive wear due to the arcing, and to avoid this, the actual opening of the circuit is between carbon blocks which may readily be renewed as necessary. When closed, the current is conducted through copper contacts, the breaker being so arranged that as it opens the copper contacts separate first and then the carbon contacts.

Current Supply.—110 volts Direct Current.

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Apparatus Required.—(1) A low and a high voltage fuse block; (2) a ceiling rosette; (3) several lengths of 3 to 5 ampere fuse wire; (4) a cartridge fuse for low current and one for heavy current; (5) an Edison fuse plug; (6) several typical circuit breakers; (7) an adjustable rheostat; (8) a lamp bank; (9) foot rule; and (10) an ammeter.

Order of Work.—1. Make a simple sketch of the fuse blocks for low and for high voltage and of the ceiling rosette, showing the fuse as well as the line terminals, and give dimensions on the sketch. Insert fuses in each of the three, and have them checked by the Instructor.

2. Connect the lamp bank in series with the adjustable rheostat and the ammeter through a fuse block to the supply switch. Starting with zero current, gradually increase the current until the fuse blows, observing the value of the current just before the circuit is broken. Repeat this test with the fuse entirely clear of the porcelain block except at the terminals, also when the fuse rests against the porcelain throughout its length. (The fuse block may be equipped with a small sized fuse wire for this test, a 3 or 5 ampere fuse being sufficient.)

3. Make a simple sketch of a low and a heavy current cartridge fuse. Take out and replace each of these fuses, observing carefully how they make contact at the terminals. Measure the supports and the length of the fuse in each case, recording the dimensions on the sketches.

4. Make a simple sketch of an Edison fuse plug and its receptacle with dimensions.

5. Sketch two types of circuit breakers. Note how they are adjusted for opening the circuit at various current values, and note the carbon blocks between which the circuit is broken, and the copper contacts between which the current flows when the breaker is closed.

6. Arrange to supply current to a bank of lamps through an ammeter and one of the circuit breakers. Set the breaker for a nominal current value and gradually increase the current by turning on the lamps until the breaker opens. With the lamps turned on attempt to close the breaker. With the lamps still on, open the main switch, close the breaker and then close the main switch. This is the regular procedure in closing a circuit

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breaker. (Caution: Do not exceed the capacity of the ammeter in this test.)

Written Report.—1. What difference was observed in the distance between fuse terminals in the fuse blocks for low and high voltage? What is the object of the longer distance for the higher voltage?

2. In item 2, *Order of Work,* was there a fixed value of current at which the 3 or 5 ampere fuse melted? What effect did the fuse touching or not touching the porcelain have on the current value at which the fuse melted? Explain briefly.

3. What advantage has the cartridge and Edison fuse over the open fuse? Has the open fuse any advantages? What provision is made in the cartridge fuse for heavy currents?

4. State briefly the operation features of the circuit breaker. Why are carbon contacts better than copper at the opening point of the breaker? Why is the breaker arranged so that the current flows through copper contacts rather than carbon after it is closed?

5. What effect was noticed when the attempt was made to close the breaker in item 6, *Order of Work,* before opening the main switch?

6. What distinguishes the blowing of a fuse or the opening of a circuit breaker under a gradual increase of current on the one hand, or by the sudden application of a heavy current on the other hand?

EXPERIMENT 6.

Study of Motor Starting Boxes.

See Articles 133, 136, 137, 138, 139, 143 and 145 in the text book.

A majority of the laboratory tests involve the starting of a motor. The purpose of this experiment is to afford an opportunity for a study of the physical make-up of common types of starting boxes and of the principles of motor starting.

Theory.—The armature winding of a motor has a very low resistance and if connected to 110 or 220-volt mains directly at starting an excessive current will flow, which is apt to damage the

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machine. As in all other cases where low resistance devices are connected to the 110 or 220-volt mains, a protective resistance must always be connected in series with the armature of a motor before connecting it to the supply mains. After applying the power to the motor it speeds up and in so doing a counter voltage is set up in the armature which acts like resistance opposing the flow of current from the supply mains. Hence, as the speed in-

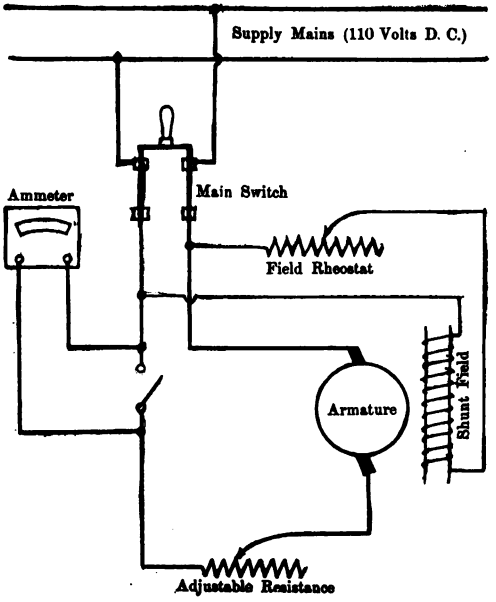

Fig. 9.—Simple connection for starting a shunt motor. Note that the shunt field circuit is entirely independent of the armature-adjustable resistance. A voltmeter is to be connected across the armature terminals.

creases, the protective resistance may be reduced and finally cut out entirely, since at normal speed the counter voltage nearly equals the applied voltage and the relatively small difference or resultant voltage sends only a moderate current through the low resistance of the armature.

The simplest form of starting resistance consists of a protective rheostat in series with the armature as shown in Fig. 9. In this diagram note that the shunt field winding is connected directly to the supply mains through a field rheostat and that the

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starting resistance has nothing whatever to do with the field circuit. (The field rheostat merely serves to vary the field current during the operation of the motor if desirable.) Other convenient modifications are made as explained in the text book articles referred to, but the underlying principle in all these starting boxes is as shown in Fig. 9.

If the field circuit is opened or if the field current is greatly reduced while a motor is in operation, the counter voltage is either reduced to zero or greatly lessened and the resistance of the armature being low, an excessive current is apt to damage the machine. As a precaution, therefore, never open the field circuit when a motor is running, and always start with all the resistance of the field rheostat cut out so that the counter voltage of the armature may quickly reach its normal value.

Current Supply.—110 volts Direct Current.

Apparatus Required.—(1) An adjustable resistance which will carry the armature current of the motor to be tested, without overheating; (2) a simple "no voltage" or "no field" release starting box; (3) a starting box with "no voltage" and "overload" release; (4) ammeter and (5) voltmeter. (Note: The current usually used in starting an unloaded motor is larger than its normal running current, hence, an ammeter must be selected that will carry the maximum starting current.

Order of Work.—1. Connect the adjustable resistance and the ameter in series with the armature of the shunt motor assigned, while the shunt field winding is to be connected directly to the supply mains through a field rheostat as shown in Fig. 9. (Caution: Be sure that the field circuit is always connected to the supply mains when current is being delivered to the armature.) With all the armature rheostat resistance cut in and all the field rheostat resistance cut out, throw in the supply switch and gradually cut out the armature resistance entirely. Note the current just at starting and after the motor is running at full speed. Also note the voltage across the armature. Record these observations on the data sheet and make a diagram of the exact connections labelling each instrument on the drawing with its laboratory number.

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2. Repeat with a portion of the field rheostat resistance cut in, noting carefully any difference in the ammeter and voltmeter readings. Record these observations.

3. Take the cover off one of the starting boxes and trace out the connections of the armature portion of the resistance. Make a diagram of these connections labelling each part in terms of the function it plays in the starting of the motor. Note also any other parts of the starting box involved.

4. Make a general inspection of the "no voltage" and the "overload" release types of starting boxes, trace their circuits and determine their functions, ascertaining such points as may not be clear, from the Instructor.

Written Report.—1. Why was the armature current higher at starting than after the motor was running at normal speed in item 1, *Order of Work?* What determines the initial current? Explain the difference in the voltmeter reading at starting and at normal speed in this same item.

2. In item 2, *Order of Work,* what effect was noticed on the starting current and voltage with the increased field rheostat resistance? Explain briefly. What do you conclude from this observation as to the proper way for setting the field rheostat at starting?

3. What is the underlying principle of all starting boxes?

4. What is the function of the "no field" or the "no voltage" release in a starting box?

5. Same for the "overload" release?

EXPERIMENT 7.

Study of Electric Lamps.

See Articles 214, 215, 218 (two articles), 219, 220 and 222 in the text book.

The object of this experiment is, first, to gain a working knowledge of the practical features of construction and operation of the important electric lamps in common use; and, second, from this study of lamps to secure a definite idea of the voltage requirements of electric circuits which supply power for the operation of lamps in practice.

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Theory.—The lamps in residence and commercial lighting are nearly always operated from constant voltage electric supply mains. At the end of the Table on page 378 of the text book, a summary is given of the effects produced on carbon incandescent lamps by a change of 1 per cent. in the voltage. For example, a fall of 1 per cent. in the voltage causes a loss of 5 per cent. in the candle-power, hence, the importance of maintaining constant voltage at the terminals of incandescent lamps.

In the operation of a shunt generator, the voltage at the terminals of the machine falls off somewhat as the machine is loaded. If this drop in the voltage is great enough to produce much decrease in the candle-power of the lamps supplied by the generator, either the field current or the speed may be varied as the load changes, thus maintaining a constant or fairly constant terminal voltage; or a series field winding may be added to the machine, thus making it a compound generator, in which the tendency of the voltage to decrease is offset by the strengthening of the field due to the current in the series winding.

Several of the experiments on the electrical features of generators will emphasize this tendency of the voltage to fall as the load is increased, and it will be well in making these subsequent observations to keep in mind why constant terminal voltage is a most important consideration in the distribution of electric power for lighting.

Among the electric lamps in common use may be mentioned the Tungsten (or Mazda) incandescent lamp; the Mercury Vapor (or Cooper Hewitt) lamp; the carbon filament incandescent lamp; and the arc lamp. Under arc lamps, may be mentioned the Flaming Carbon arc used in some cases for street lighting and for commercial or factory lighting; the Metallic Flame or Magnetite arc lamp used mainly for street lighting; and the older Enclosed Carbon arc lamp.

Current Supply.—110 volts Direct Current.

Apparatus Required.—(1) A board on which are mounted the parts of a carbon filament incandescent lamp; (2) a Tungsten (or Mazda) lamp; (3) Focusing, Intensive and Extensive Holophane prismatic reflectors with prints of the respective distribution of light curves; (4) a form "O" and form "H" shade holder; (5) a Mercury Vapor (or Cooper Hewitt) lamp with a

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diagram of the internal electrical connections; (6) one or more of the principal types of arc lamps with diagram of the internal electrical connections.

Order of Work.—1. Make a sketch of the various parts (labelling each) involved in the manufacture of carbon incandescent lamps.

2. Make a simple diagram of a tungsten lamp showing the method employed in mounting the filament.

3. Make a simple sketch of the Focusing, Intensive and Extensive Holophane Prismatic reflectors, showing the general shape of each, also the approximate distribution curves of each.

4. Make a sketch of the form "O" and of the form "H" shade holder giving dimensions on the sketches.

5. Make a diagram of the electrical connections of the Mercury Vapor lamp, recording the rating of the lamp in volts, amperes and watts.

6. Connect the Mercury Vapor lamp through a suitable rheostat to the supply mains and observe its action at starting.

7. Make a diagram of the electrical connections of the arc lamp (or lamps) available, recording the rating in volts, amperes and watts.

8. Connect the arc lamp (or lamps) through a suitable rheostat to the supply mains and observe the action at starting, also the method of feeding the carbons as they are consumed.

Written Report.—1. Describe briefly the principal items in the manufacture of carbon incandescent lamps.

2. What is the function of the vacuum?

3. Why is a reflector a necessary auxiliary with the Tungsten lamp for its most economical operation?

4. For what purposes are each of the Holophane reflectors best suited?

5. Aside from supporting the reflector, what other function has the shade holder in connection with Tungsten lamps?

6. Describe briefly the method of operation of the Mercury Vapor lamp.

7. Same for the arc lamp (or lamps).

8. Between the generator in the electric power station and distant lamps there is apt to be an appreciable voltage drop which depends on the current flowing through the lines. If the attend-

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ant in the power station regulates the voltage of the generator by a voltmeter which indicates the voltage in the station, how is constant or fairly constant voltage assured at the distant lamps in residence lighting work?

EXPERIMENT 8.

Building Up of Voltage in Shunt Generator.

See Articles 117, 118, 119 and 120 in the text book.

In many of the laboratory experiments as well as in practical generator operation, it is necessary to understand the conditions which must be met in order that a self-excited generator may build up to its normal voltage at starting. The object of this experiment is to gain a working knowledge of these conditions and how to meet them.

Theory.—Electric generators may be classed as to the production of the necessary magnetic field under the head either of separate or self excitation. For separate excitation, the field winding is connected directly to the supply mains as shown in Fig. 10 so that the field current is derived from a generator already in operation, and the voltage of the machine rises to its normal value as soon as the armature is brought up to its normal speed because the magnetism is at its full value at the start. In this case the field magnetism is practically independent of the operation of the machine, being dependent on the voltage of the supply mains and on the hand manipulation of the field rheostat.

For the self excitation of a shunt generator, the field winding is connected to the armature terminals through a field rheostat as shown in Fig. 10, and the voltage of the machine even after the armature is brought up to normal speed may sometimes amount only to the several volts due to residual magnetism in the field poles, that is, to the small amount of magnetism left over from the last time the machine was in operation. Since the field current and, hence, the magnetism depends on the voltage induced in the armature in this case, and since the voltage itself is dependent on the field magnetism produced by the field current, it is obvious that the generation of electromotive force must be cumulative, starting from the few volts produced by

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residual magnetism and rising to the normal voltage of the machine.

It will further be obvious that no electromotive force can be induced in a self-excited generator (connected for self excitation) unless there be a small amount of residual magnetism in the field poles to begin with. When machines are in regular operation with an occasional shut-down, there is usually sufficient

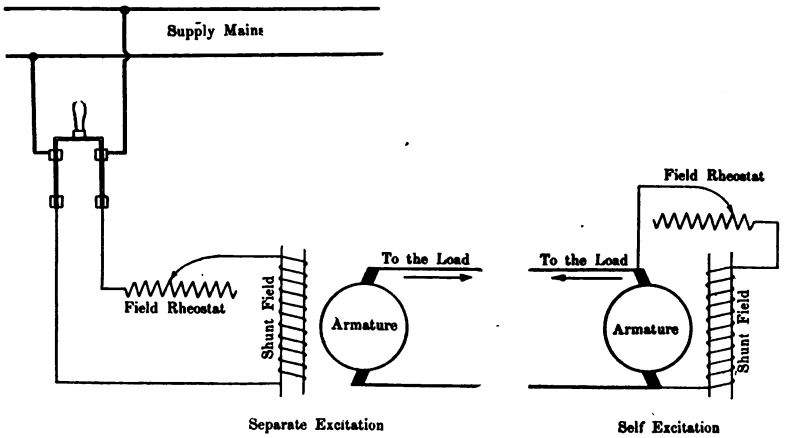

Fig. 10.—Two methods of exciting the field of a shunt generator: (a) separate excitation is shown to the left; and (b) self excitation to the right.

residual magnetism in the fields for the machine to build up each time it is started. In practice, direct current generators are usually operated with self excitation.

The principal condition to be met for building up is that the electromotive force produced at starting by the rotation of the armature in the weak residual magnetism be such that the current it produces in the field winding shall aid or increase the residual magnetism. If this condition is fulfilled, the increased magnetism produces an increased electromotive force which, in turn, produces an increased field and the electromotive force soon rises to its full normal value being limited by the saturation of the field magnet iron.

If the machine fails to build up, the necessary favorable conditions can usually be secured either by reversing the connection

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of field winding to armature terminals or by running the armature in the opposite direction.

Other causes which sometimes affect the building up of a machine may be due to poor contact of the brushes on the commutator, to the fact that the field rheostat resistance is all cut in, or to too little residual magnetism.

Current Supply.—110 volts Direct Current.

Apparatus Required.—(1) A shunt generator; (2) reversing switch for readily interchanging the connections of field winding to armature terminals; and (3) a voltmeter with a range slightly above the rating of the generator.

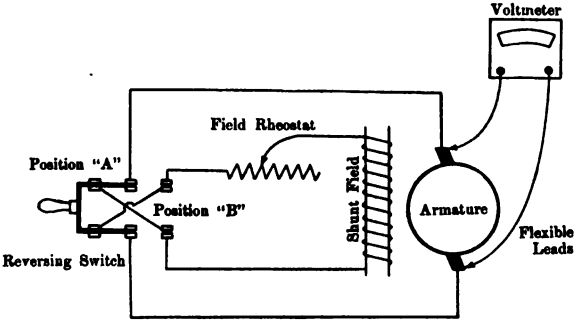

Fig. 11.—The reversing switch is a convenient means for reversing the terminals of the field winding as connected to the armature terminals. (The student should trace the circuit for the two positions of the reversing switch to determine how the connections are reversed.)

Order of Work.—Make a diagram of the exact connections for the following items labelling each instrument with its laboratory number on the drawing.

If the machine fails to build up in all of the following cases on first or second trial, temporarily disconnect the field from the reversing switch and connect it to the supply mains for a short time so as to insure the necessary residual magnetism in the field magnets. Then proceed as directed under the following heads:

1. Arrange the assigned shunt generator for self excitation as shown in Fig. 11. The reversing switch inserted between the field winding and the armature terminals provides a convenient means for reversing the connections of field to armature.

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2. With the field disconnected (reversing switch open) drive the machine at normal speed and observe the electromotive force at the armature terminals produced by residual magnetism. Record the electromotive force (volts) and the speed as in Form 6.

3. Throw in all the field rheostat resistance, close the reversing switch to the arbitrary position "A" (this letter should be marked in chalk on one end of the switch for reference) and with the armature rotating at normal speed in a forward[1] direction, gradually cut out the field rheostat. Observe the initial and final values of electromotive force produced, that is, before and after

No.	Position of Reversing Switch	Direction of Rotation	Field Rheostat Resistance	Speed (To be Kept Constant)	Volts
1	Open	Forward	——		
2	"A"	"	In		
3	"A"	"	Out		

Form 6.

cutting out the field rheostat resistance, the speed, and the position of the reversing switch as in Form 6.

4. Same, throwing the reversing switch in the opposite direction (mark this second position on the other end of the switch "B"). Note that this second position of the reversing switch changes the connections of field to armature.

5. Same as 3 with armature rotating in a backward direction.

6. Same as 4 with armature rotating in a backward direction.

7. Note carefully what effect is produced on the building up in those cases where the conditions are favorable for building up, except that the field rheostat is all cut in.

Written Report.—1. To what is the electromotive force as observed in item 2, *Order of Work,* due?

[1]The terms forward and backward as referred to direction of rotation are of course arbitrary.

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2. In that case, under items 3 and 4, *Order of Work,* where the machine built up to its normal voltage, explain briefly to what the increase of voltage was due. In the other case, what prevented the machine from building up?

3. Where a shunt generator fails to build up, why should reversing the direction of armature rotation be favorable to building up?

4. Why should excessive brush resistance tend to prevent building up even when the connections of field to armature or the direction of armature rotation are favorable?

5. As a summary of the observations, explain briefly the various steps which should be taken if a shunt generator fails to build up. If the fault is due to a lack of, or insufficient residual magnetism, how could this lack be determined by a simple test observation? What would happen if one of the field coils be reversed?

EXPERIMENT 9.

Electrical Features of the Shunt Generator.

See Article 121 in the text book, also the *Theory* under Experiment 7 in the Manual.

The object of this experiment is (a) to make a study of the factors by means of which the voltage of a generator may be varied or controlled; (b) to observe the tendency of the terminal voltage to decrease with increasing output; and (c) to take the observations for the calculation of the so-called regulation of the machine.

Theory.—By the term voltage control is meant the changing of conditions exterior to the generator for the purpose of maintaining some given value of voltage at the terminals of the machine at various loads. Thus, by changing the field rheostat resistance (by hand), the voltage of the machine may be varied over quite a wide range; or by changing the speed of the machine (by changing the speed of the driving engine) the voltage may be varied.

On the other hand, as the output (load) of the shunt generator increases, for example, by turning on more of the lamps it supplies, the voltage (RI) drop in the armature increases (be-

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cause I increases) and the terminal voltage falls off. This drop in voltage obviously depends on an inherent property of the machine, namely, the amount of fixed resistance in the armature winding. Changes which occur in the terminal voltage of a generator, due to inherent properties, are referred to as voltage regulation to distinguish them from changes which are made by varying conditions exterior to the machine, and referred to as voltage control.

The principal means for controlling the voltage of a shunt generator are hand variations of the field rheostat resistance, and changes in the speed by variations in the speed of the driving engine.

The main items which govern inherent changes in the voltage (that is, the regulation) are the resistance of the armature winding, together with slight magnetic reactions in the armature which tend to decrease the effective magnetic field and, hence, the voltage.

The percentage regulation of the generator is defined as the difference between the full load and the no-load voltage divided by the full load voltage at constant speed (obviously this result must be multiplied by 100 to express it as a percentage). Thus, if the full load and the no-load voltages are 100 and 110 respectively, the regulation is equal to 10 per cent. If, in this case, the numerical value of regulation be greater, indicating a larger drop in voltage at full load, it is apparent that the numerically greater value of regulation indicates a certain inferiority in the construction of the machine.

Current Supply.—From the Shunt Generator assigned.

Apparatus Required.—(1) Shunt generator driven by a variable speed motor; (2) field rheostat; (3) speed indicator; (4) double-pole single-throw switch; (5) lamp bank to be used as a load; (6) an ammeter; and (7) a voltmeter.

Order of Work.—1. Connect the field rheostat between the field winding and the armature terminals for shunt (self excitation) operation. Drive the generator at its normal speed, and maintaining constant speed, observe and record the terminal voltage at no-load for 5 different positions of the field rheostat handle, starting with all the resistance cut in and gradually decreasing

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the resistance. Use Form 7. (Note: Although not shown in Fig. 12, it will be an advantage to connect an ammeter in the field circuit as a guide to the changes which take place in the field current in item 1 as the field rheostat is adjusted; to insure in item 2 that the field current remains constant; and as a guide to the changes in the field current in items 3 and 4.)

No.	Constant Speed		Constant Field Current		No.	Constant Speed	
	Position of Field Rheostat	Volts	Speed	Volts		Output Amperes	Volts
1	1 (All In)				1	(Zero Load)	
2	2				2	(Half Load)	
3	3				3	(Zero Load)	

Form 7.

2. Adjust the terminal voltage by means of the field rheostat for its normal value at normal speed and, leaving the field rheostat untouched, reduce the speed to a value 20 per cent. below normal, and observe and record the terminal voltage at no-load for the low speed and for 4 other values of speed, gradually increasing it until somewhat above normal.

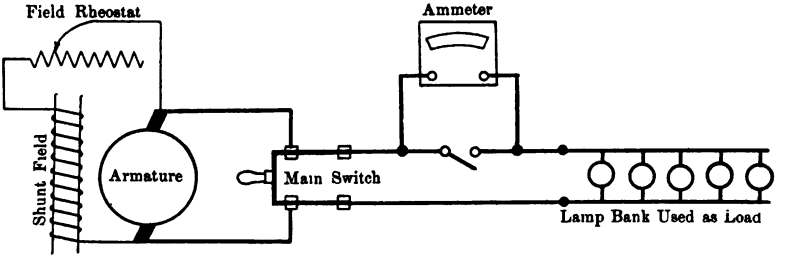

Fig. 12.—Diagram for loading a shunt generator. The lamps may conveniently be disconnected from the machine by the main switch. A voltmeter is to be connected to the armature terminals.

3. Connect the lamp bank through the double-pole single-throw switch and an ammeter to the armature terminals as shown in Fig. 12. With the switch open and with normal speed adjust the voltage to its normal value by means of the field rheostat, after which the field rheostat is to be left untouched. Turn off

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all the lamps, close the switch, and then turn on enough lamps to load the machine to about 50 per cent. of its capacity (see name plate on the machine). Keeping the speed at its normal value throughout, observe and record the terminal volts before and after throwing on the lamps. Use Form 7.

4. Same as 3 except that full load current is to be used.

Written Report.—1. In item 1, *Order of Work,* why do the changes of the field rheostat change the terminal voltage? What is the range in the control of voltage by this means as observed?

2. Same, for speed change in item 2, *Order of Work.*

3. In item 3, *Order of Work,* what causes the voltage to drop as the load is thrown on the machine? How does this drop in voltage for half and for full load compare?

4. From the observations under item 4, *Order of Work,* calculate the percentage regulation of the machine.

5. From the observations in this experiment, what are your conclusions as to the adaptability of the shunt generator for electric lighting?

EXPERIMENT 10.

Shunt and Separate Field Excitation Compared.

See the *Theory* under Experiment 8 in the Manual.

The object of this experiment is to afford an opportunity for a study of the factors entering into the changes of voltage due to loading a shunt wound generator both for shunt (self) and separate field excitation.

Theory.—In the shunt wound generator connected for self excitation (shown in Fig. 10), as the load is increased the volts (RI) drop in the armature increases and, hence, the terminal voltage decreases. With each decrease in terminal voltage the shunt field current, equal to E/R, falls off, and as a consequence the field magnetism and the induced armature voltage in turn are reduced. Hence, a decrease in terminal voltage produces what may be termed a cumulative reduction of terminal voltage in the shunt self-excited machine.

In the shunt wound generator connected for separate excitation (shown in Fig. 10), as the load is increased, the volts (RI) drop in the armature increases and, hence, the terminal voltage

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decreases, however, with the following difference: The field current in this case is independent of the terminal voltage of the armature, being connected to the constant voltage supply mains, and, hence, any decrease in the terminal voltage of the armature has no effect on the field current. For this reason, the decrease in terminal voltage is less for a given load current in the case of separate than for shunt (or self) excitation.

Current Supply.—110 volts Direct Current.

Apparatus Required.—(1) Shunt generator; (2) double-pole double-throw switch for readily connecting the field winding

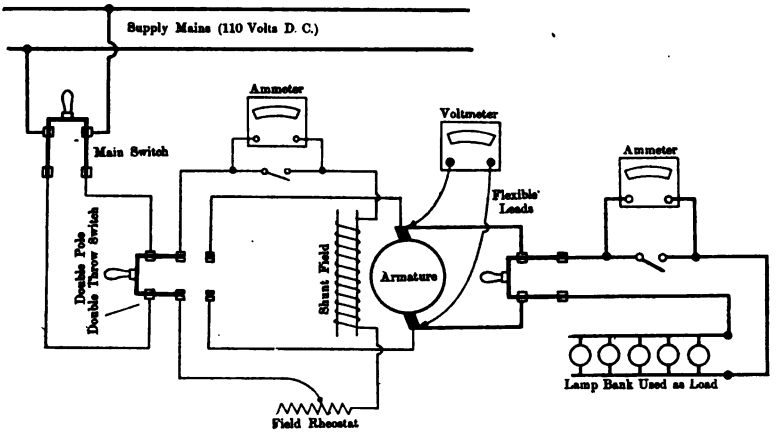

Fig. 13.—A study of self and separate excitation. The double-pole double-throw switch is a convenient means for quickly connecting the field winding either to the armature terminals or the supply mains.

either to the supply mains or the armature terminals; (3) double-pole single-throw switch for connecting the armature terminals to the load of lamps; (4) field rheostat; (5) speed indicator; (6) lamp bank to be used as the load; (7) ammeter for the field circuit; (8) ammeter for the main circuit; and (9) voltmeter.

Order of Work.—1. Connect the field winding through the double-pole double-throw switch and an ammeter, as shown in Fig. 13, for self or separate excitation. Connect the armature terminals through the double-pole single-throw switch and an ammeter to the lamp bank. With the load switch open, and the field winding connected to the armature terminals, drive the

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machine at normal speed and see that it builds up to normal voltage, making the required adjustments by means of the field rheostat. Throw the field switch for separate excitation and see that the instruments read in the same direction for both self and separate excitation. If not, reverse one set of connections.

2. Throw the field switch for self excitation, and with normal speed and normal no-load voltage, throw on ¼ full load current, keeping the speed constant and leaving the field rheostat untouched after the preliminary adjustment for normal no-load voltage. Observe and record the terminal voltage, field current, load current and speed before and after throwing on the ¼ load current. Use Form 8.

(Speed Constant Throughout)

No.	Self Excitation				Separate Excitation			
	Volts	Field Amperes	Load Amperes	Speed	Volts	Field Amperes	Load Amperes	Speed
1			(Zero Load)					
2			(Quarter Load)					
3			(Zero Load)					
4			(Half Load)					

Form 8.

3. With the load switch open throw the field switch for separate excitation and repeat the observations outlined under 2.

4. Same as 2 and 3, except that ½, ¾ and full load current are to be used in turn.

Written Report.—1. Why does the voltage fall off more for self than for separate excitation in items 2, 3, and 4, *Order of Work.*

2. Plot a curve using volts as ordinates and load current as abscisses for zero, ¼, ½, ¾, and full load current, both for self and for separate excitation.

3. Why do the values of field current change in the case of self excitation, but not for separate excitation (assuming constant voltage supply mains)?

4. Is there more likelihood of a self-excited shunt generator having its polarity reversed on starting up than a separately excited machine? Why? (See Article 118 in the text book.) Give

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a case where such a reversal of polarity might be a serious disadvantage, and explain briefly.

5. If the speed, electromotive force and current to a lamp bank are the same, what are the relative field currents by self and separate excitation?

EXPERIMENT 11.

Electrical Features of the Compound Generator.

See Article 122 and the example at the end of Article 122 in the text book, also the *Theory* under Experiment 9 in the Manual.

The object of this experiment is (a) to observe the tendency of the series field winding in a compound generator to offset the decrease of terminal voltage due to armature volts drop (RI); (b) to note the effect on the terminal voltage produced by changing the series field current (by means of a shunt) for a given output current; (c) to note the effect on the compounding by a change in the running speed of the machine, the initial no-load voltage being the same as in (a); and (d) to take the necessary observations on the generator operated as a shunt machine (the series winding disconnected) for a determination of the number of series turns required for compounding.

Theory.—Like the shunt generator, as the output of the compound generator increases, the terminal voltage tends to decrease due to the volts (RI) drop in the armature winding. The series winding, however, on the compound generator through which all or most of the output current flows, being wound on the field magnets with the shunt windings, produces a magnetic field which is nearly proportional to the load current. Hence, when the armature RI drop is large, that is, when the output current is large, the tendency of the terminal voltage to decrease is compensated for by the additional field magnetism produced by the series winding, which causes a larger voltage to be induced in the armature.

Obviously, by changing the number of series turns or by varying the proportion of the full load current which flows through the series winding, the degree of this compensating effect may be correspondingly changed. In that case where the full load and no-load voltages are the same in value, the machine is said to

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be flat compounded. Where the full load voltage is greater than the no-load voltage, the machine is said to be over-compounded.

In Experiment 9 it was shown that the terminal voltage of the shunt generator is changed by variations in the field current. As the load on a shunt generator increases, the field current might be increased sufficiently for each increase in output current to maintain a constant terminal voltage throughout the range from no-load to full load, provided there was enough margin in the field rheostat resistance to permit of the necessary increases in the field current. As shown in the foregoing, this same effect may be produced by means of a series winding placed on the magnets in addition to the shunt winding, the necessary increases in field magnetism being produced by the current output which flows through the series turns.

The ampere-turn (one ampere flowing through one turn of wire) is a common unit of magnetizing effect. Thus, if 2 amperes flow through 5,000 turns of wire, the magnetizing effect is equivalent to 1 ampere through 10,000 turns. In the latter part of this experiment, the generator is operated as a shunt machine at normal voltage and speed (speed maintained constant throughout). Starting with no load, the current output is increased in steps, and the field rheostat is adjusted at each observation for the initial terminal voltage value, in other words, the voltage is maintained constant throughout by the hand manipulation of the field rheostat.

As an illustration, if the shunt field current required to produce the initial voltage, at full load, is 1.5 amperes, while at no-load the field current required is 1.0 ampere, this increase of 0.5 ampere required at full load, multiplied by the number of shunt field turns (assumed as 10,000 this product is $0.5 \times 10{,}000 = 5{,}000$ ampere-turns) represents the additional field excitation required at full load in order to maintain constant terminal voltage.

By the aid of a series winding through which the full load current flows (assumed to be 100 amperes) this same magnetizing effect, that is, the additional 5,000 ampere-turns, may be secured by the use of 50 series turns. Hence, the effect at full load is the same whether 0.5 ampere is added to the no-load value of shunt field current through 10,000 shunt turns, or whether the full load current of 100 amperes flows through 50 turns wound on the magnets as a series winding in addition to the shunt wind-

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ing. Obviously the series turns produce no effect on the excitation at no-load if connected as shown in Fig. 14.

Current Supply.—From the Componnd Generator assigned.

Apparatus Required.—(1) Compound generator driven by a variable speed motor; (2) field rheostat; (3) speed indicator; (4) double-pole single-throw switch; (5) low resistance to be used

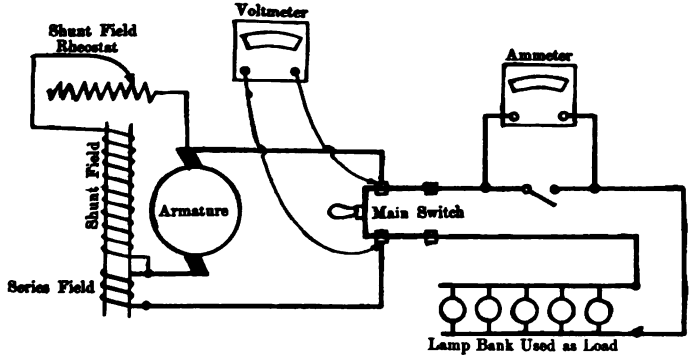

Fig. 14.—Compound generator, using the *short shunt* connection. Note that no current flows through the series winding when the main switch is open. (Note: This diagram shows the general scheme of connections. As indicated by the windings, the machine would be differentially compounded, while in practice it is ordinarily arranged for cumulative compounding, that is, the series winding would be the reverse of that shown.)

as a shunt around the series field; (6) lamp bank to be used as a load; (7) two ammeters; and (8) a voltmeter.

Order of Work.—1. With the generator arranged for compound operation, connect the lamp bank through the double-pole single-throw switch and an ammeter to the machine terminals, as shown in Fig. 14. With the switch open and with normal speed, adjust the voltage to its normal value by means of the shunt field rheostat. Turn off all the lamps, close the switch, and then turn on enough lamps to load the machine to about 50 per cent. of its capacity (see name plate on the machine). Keeping the speed at its normal value throughout, record the terminal volts and load current before and after throwing on the lamps. The field rheostat is to be untouched after the initial adjustment.

2. Same as 1, except that full load current is to be used.

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3. Same as 2, except that the low resistance shunt is to be connected to the terminals of the series winding, and its resistance varied until the terminal voltage is 5 per cent. lower at full load than in the observations of item 2.

4. Same as 1 and 2, except that the machine is to be run 10 per cent. below rated speed throughout, and the shunt current adjusted to give normal no-load voltage, that is, the same value as used in items 1 and 2. (Note: Due care must be taken to indicate on the data sheet, to which speed the observations of items 1, 2 and 4 refer, in each case.)

5. The generator assigned is to be arranged for shunt operation, that is, the series winding is to be disconnected, and the machine is to be connected to the lamp bank as shown in that

No.	Terminal Volts (Constant)	Field Amperes	Output Amperes	Speed (Constant)
1			(Zero Load)	
2			(Quarter Load)	
3			(Half Load)	

Form 9.

portion of Fig. 13 involving self excitation, that is, omit the two terminals on the left of the field switch shown in this illustration.

6. Starting at no load (load switch open) adjust the voltage to its normal value at normal speed and observe the terminal volts, field current, output current (=zero) and speed. Use Form 9.

7. Turn off all the lamps, close the switch, and then turn on enough lamps to equal ¼ of the rated capacity of the machine, adjusting the field rheostat until the terminal voltage is the same as in 6 and keeping the speed constant. Observe the terminal volts, field current, output current and speed as in Form 9.

8. Same as 7, for ½, ¾, full load and ¼ overload in turn, maintaining the speed constant and adjusting the field rheostat for constant terminal voltage in each case.

9. Ascertain and record the number of shunt field turns on the generator.

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Written Report.—1. In item 1, *Order of Work,* what causes the voltage to be maintained, notwithstanding the effect of *RI* drop in the armature? How does the terminal voltage, under load, compare in items 1 and 2, *Order of Work,* for half and full load current output?

2. What effect does the shunt, around the series field terminals, have on the terminal voltage for a given load output?

3. What would the effect be of increasing the number of series field turns, on the full load voltage? On the no-load voltage?

4. When the compound generator is run 10 per cent. below normal speed in item 4, *Order of Work,* with the shunt current adjusted to give normal no-load voltage, how does the compounding compare with that at normal speed? Explain.

5. Plot a curve using the field current as ordinates and output current as abscisses, from the observations in items 6, 7 and 8, *Order of Work.*

6. Calculate the number of series turns necessary for flat compounding.

7. If the speed had fallen off 10 per cent. between a set of observations, what effect would this have had on the necessary increase of field current to bring the voltage up to normal value before taking the next set of observations in items 6, 7 and 8, *Order of Work?*

8. If it was desired to calculate the series turns necessary to over-compound this machine by 5 per cent. at full load, what additional observations would have been necessary in the experiment in items 6, 7 and 8, *Order of Work?*

9. Why may it be an advantage to have the terminal voltage of a compound generator higher at full load than at no-load in some cases? Explain.

10. From the observations in this experiment, what are your conclusions as to the adaptability of the compound generator for electric lighting and power service? Are generators usually shunt or compound?

EXPERIMENT 12.

Study of the Storage Battery.

The object of this experiment is to gain a working knowledge of the practical construction and operation of the storage battery. While a knowledge of the principles of construction and of

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the theory of operation is an advantage, in this case it is possibly more important to understand something of the practical operation and, hence, this feature will be emphasized somewhat to the exclusion of the more theoretical items.

Theory.—The storage cell is commonly known as a secondary cell on account of the necessity of charging before taking current from a battery made up of a number of such cells. The term secondary further distinguishes the storage battery from the primary cell where the electromotive force and current are the result of direct chemical action on the elements which make up the battery.

There are certain practical points regarding the operation of storage batteries which are referred to in the text book, but the student should send a post card to the manufacturer of the battery examined, with a request for the circular dealing with the operation of the given battery. It is suggested that this circular be attached to the *Written Report* for future reference.

Apparatus Required.—(1) Several grids from a storage battery; (2) a regular storage battery equipment (found in most laboratories); (3) foot rule; (4) voltmeter; and (5) a hydrometer for measuring the specific gravity of the electrolyte.

Order of Work.—1. Make an inspection of the storage battery grids available, sketching same with dimensions. Describe briefly the construction of these plates on the data sheet.

2. Inspect the storage battery equipment in the Laboratory, measuring approximately the size of the grids and the size of the glass jars. Note the height of the electrolyte in the jars, and the general method of supporting the jars and of making connections between the cells. Make sketches or describe these various items briefly on the data sheet.

3. Measure the voltage of one or two of the cells separately and of the entire battery, recording these observations.

4. Measure the voltage of the battery when *delivering* various currents and when *receiving* various currents.

5. Count and record the number of cells in the battery, and measure the temperature and the density of the electrolyte.

6. Secure the name and address of the manufacturer of the battery examined.

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Written Report.—1. What is the active material in the grids inspected in item 1, *Order of Work?* How is this active material deposited and held on the plates in the manufacture of the battery? Of what metal are the supporting plates constructed?

2. How are the jars of the battery mounted, and what precaution is taken in the battery room in case of leakage?

3. What is the average electromotive force per cell of the battery inspected? What is the average rate of discharge in amperes allowable based on an 8-hour rate? (See Article 200 in text book.)

4. What is the effect on the battery terminal voltage when delivering various currents?

5. Same, when receiving various currents?

6. What is the general procedure in charging a battery?

7. What precautions must be observed when a battery is to be unused for several months?

8. How can it be determined when a battery requires charging and when it is sufficiently charged?

9. What results if a battery is discharged or charged at too rapid a rate?

(It is suggested that items 6, 7, 8 and 9, of *Written Report,* be answered by the aid of the pamphlet secured by the student from the manufacturer of some standard battery equipment, preferably the one inspected.)

EXPERIMENT 13.

Study of the Wiring in the Laboratory.

In this Experiment the opportunity is given for gaining information in regard to methods of distributing the electric current for lighting and power throughout a given building. The general items connected with such work are here given preference over details and such few details as are desired will be mentioned in the following directions under appropriate heads.

Theory.—Interior wiring for the supply of electric lamps is arranged for by the constant voltage system of distribution. This means that each lamp must receive approximately the same voltage no matter how many are turned on and, hence, the size of

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wires must be large enough in central portions of the building where heavy currents flow, as to cause only a low voltage (*RI*) drop, while in more remote portions of the building the size of wires may be smaller. Power mains must also follow this general scheme.

An ordinary method used for lighting circuits is to run heavy wires from the main switch (or bus bars) to panel (switch) boxes on the various floors, and from these panel boxes individual circuits of 660 watts maximum, are run to the various rooms. The 660 watts limit is fixed by the National Board of Fire Underwriters as a safeguard against fire risk. Thus, if 100 watt tungsten lamps are used, each circuit is limited to 6 lamps.

Order of Work.—1. In the room assigned, observe and record the number, size and type of lamps and reflectors used; the area of the floor space in square feet; the mounting height and spacing of the lamps; and the arrangements for other uses of current.

2. Record by sketches and explanation the method of mounting the lamps at the ceiling; the switching arrangement; and the number of lamps per switch.

3. Note the general arrangement of conduit or wiring to this room from the panel box, and inspect the panel box, making a sketch and giving dimensions on the drawing; note the fuses and circuit breakers; also the kind of insulation and the size of the wire used.

4. Note how the conduit is run to the panel box from the main switch board, recording such data as may be necessary for an explanation in the *Written Report*.

5. Note and record the number of switches on the main switch board which supply lighting and service outlets throughout the building.

6. From plans or measurements determine and record the approximate number of square feet area of the floors in the building.

Written Report.—1. How many watts per square foot are used for lighting in the room assigned? What is the ratio of spacing to mounting height of the lamps, and what effect does this have on the distribution of the light throughout such a room?

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2. Describe briefly the general scheme used in running the wires from the main switch board to the lamps in the building inspected.

3. Same, for the service outlets.

4. Based on the watts per square foot used for lighting in the room inspected, and on the total floor area in the building, how many watts are required as a maximum for lighting the Laboratory? Express this result also in kilowatts.

5. Does the generator which supplies the lamps need to have a capacity equal to this maximum requirement? (Suggestion: Give due weight in answering this question to the average number of lamps which may be used at any one time in such a building.) What size of generator would you consider about proper for such a lighting load?

EXPERIMENT 14.

Shunt Motor Speed Features.

See Articles 129, 132, 133, 135, 139 and 145 in the text book, also the *Theory* under Experiments 4 and 6 in the Manual.

The object of this experiment is (a) to make a study of the factors by which the speed of the shunt motor may be varied or controlled; (b) to observe the tendency of the speed to decrease with increasing load; and (c) to take the observations for the calculation of the so-called regulation of the machine.

Theory.—By the term speed control is meant the changing of conditions exterior to the motor for the purpose of obtaining desired speed values. Thus, changing the field rheostat (by hand), the speed of the machine may be varied over quite a wide range; or changing the supply voltage across the armature terminals (by means of a rheostat in series with the armature or otherwise), the speed may be varied.

On the other hand, as the load supplied by the motor is increased, for example, when an added load is placed on a hoist being raised by the machine, the motor slows down and thus permits an increased current to flow into the armature necessary for developing the additional mechanical force (or torque). The

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field winding being connected to constant voltage supply mains, receives the same current as before in this case. This drop in speed depends on inherent properties of the motor, chief of which is the resistance of the armature winding. Changes which occur in the speed due to inherent properties, are referred to as speed regulation to distinguish them from changes which are made by varying conditions exterior to the machine, and referred to as speed control.

Among the principal means for controlling the speed of a

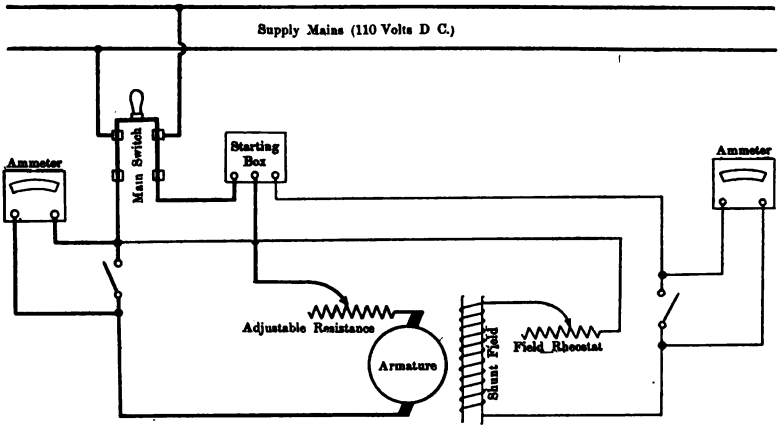

Fig. 15.—Shunt motor. The "adjustable resistance" is not ordinarily required in addition to the starting box, but is here used merely for convenience in varying the voltage across the armature terminals.

shunt motor is by the hand manipulation of the field rheostat resistance; and that by changing the voltage across the armature terminals of the machine by a rheostat in series with the armature only.

The main items which govern inherent changes in the speed (that is, the regulation) are the resistance of the armature winding together with slight magnetic reactions in the armature which tend to modify the effective magnetic field produced by the field winding.

The percentage regulation of the speed is defined as the difference between full load and no-load speed divided by the full load speed, supply voltage and field current remaining unchanged. (Obviously this result must be multiplied by 100 to ex-

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press it as a percentage.) Thus, if the full load and no-load speeds are 1,500 and 1,650 revolutions per minute respectively, the regulation is equal to 10 per cent. If the speed at full load falls off more than indicated in this case, the numerical value of the regulation will be greater and, hence, will indicate a certain inferiority in the construction of the machine.

Current Supply.—110 or 220 volts Direct Current.

Apparatus Required.—(1) Shunt motor; (2) starting box; (3) field rheostat; (4) armature rheostat; (5) speed indicator; (6) brake to be used for loading the motor; (7) ammeter for the field circuit; (8) ammeter for the armature circuit; and (9) voltmeter.

No.	Position of Field Rheostat	Speed	Armature Amperes	Position of Armature Rheostat	Speed	Armature Amperes	Armature Amperes	Speed
1	1 (All Out)		(For No Load)	(Out)		(Zero Load)	(Zero Load)	
2	2		"	(In)		"	(Quarter Load)	
3	3		"	(Out)		(Full Load)	(Half Load)	
4	4		"	(In)		"		

Form 10.

Order of Work.—1. Connect the motor to the supply mains as shown in Fig. 15. With the field rheostat all cut out, start the motor by means of the starting box and cut out all the armature rheostat resistance. With the motor unloaded, observe and record the speed for this and for 4 other positions of the field rheostat, gradually increasing its resistance until the motor speed is considerably above normal. Use Form 10.

2. With the motor unloaded, adjust the field rheostat for normal speed, and observe the speed for no resistance and for a fairly high resistance inserted in the armature circuit, leaving the field rheostat untouched after the initial adjustment.

3. Same as 2 except that the motor is to be loaded by the brake until the armature current is a fair proportion of the full rated current. (Note: To be most instructive the resistance inserted in the armature circuit for the second observation in items 2 and 3 should be the same value in each case.)

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4. Adjust the motor for normal speed at no load by the field rheostat after reducing the armature rheostat resistance to zero, and observe and record the speed for zero, ¼, ½, ¾ and full load armature currents in turn (assume full load armature current as equal to the current rating on the name plate of the machine). Leave the field rheostat untouched throughout these observations after the initial adjustment.

Written Report.—1. In item 1, *Order of Work,* why does the speed increase as the field rheostat resistance is increased? What is the range of speed control by means of the field rheostat method as observed?

2. In items 2 and 3, *Order of Work,* why is the speed affected more by the armature rheostat when the motor is loaded than when unloaded?

3. From the observations in item 4, *Order of Work,* plot a curve using speed as ordinates and armature current as abscissas.

4. Calculate the percentage speed regulation of the motor.

5. The torque of a motor depends on the field magnetism effective in the armature and on the armature current. When the field magnetism was weakened in item 1, *Order of Work,* the motor speeded up. Should not a weakened field cause less torque and, hence, less rather than more speed? Explain. (See Article 135 in the text book.)

6. To what is the decrease in speed with increased load due as observed in item 4, *Order of Work?*

EXPERIMENT 15.

Efficiency of a Shunt Motor by the Brake Method.

See Article 158 in the text book.

The object of this experiment is to determine the efficiency (output divided by input) of a shunt motor by measuring the mechanical output and the electrical input at various loads.

Theory.—The efficiency of the electric motor like that of other machines is defined as the ratio of output to input. In a determination of the efficiency, therefore, it is necessary to measure the mechanical output as indicated by a brake attached to the

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pulley, and for each value of output thus observed to measure the electrical input.

In the actual calculation of the efficiency, the mechanical output in horse-power may readily be transformed by multiplying the horse-power by 746, the number of watts in one horse-power, and the output is thus expressed in the same units as the input.

Since the losses in a motor are partly constant (or nearly constant) and partly variable, and since the variable losses (RI^2) in the armature winding vary as the square of the current, it will be obvious first, that the constant losses play a much larger part for low loads, thus reducing the efficiency at low loads as compared to full load, and second, that the RI^2 loss in the armature, increasing as the square of the current, becomes quite large in proportion for high current values and, hence, the efficiency tends to fall off after a certain maximum value has been reached near full load.

Current Supply.—110 or 220 volts Direct Current.

Apparatus Required.—(1) Shunt motor; (2) starting box; (3) field rheostat; (4) speed indicator; (5) brake to be used for loading the motor; (6) ammeter; and (7) voltmeter.

Order of Work.—1. Connect the motor to the supply mains in the usual manner, arranging the ammeter to measure the entire current input to both field and armature.

2. Start the motor and bring it to normal speed at no load, that is, with the brake detached completely from the pulley. Observe and record the input (volts and amperes).

3. Attach the brake and tighten until the ammeter indicates ¼ the full rated current (see name plate on the machine). Observe and record the torque exerted at the pulley and the volts and amperes input.

4. Same as 3, for ½, ¾, full load, and 1¼ and, if practicable, 1½ of full load current in turn.

Written Report.—1. Calculate the efficiency of the motor in per cent. from the observations in items 2, 3 and 4, *Order of Work.*

2. Plot a curve, using the efficiency as ordinates, and the input current as abscissas.

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3. Explain briefly the general shape of this curve, that is, why it follows the form taken.

4. Name the constant and variable losses in a generator or motor. (See Article 155 in the text book.)

5. Why should the constant losses in a motor cause the efficiency to be low at low loads?

6. Why does the RI^2 loss in the armature cause a reduction of the efficiency after a certain maximum value near full load?

7. How could the armature current be found mathematically for a given machine at which the efficiency is a maximum?

EXPERIMENT 16.

Series Motor Speed Features.

See Articles 140, 141, 142, 143, 144 and 145 in the text book.

The object of this experiment is to make a study of the speed of a series motor as affected by the load.

Theory.—The torque of a series motor is proportional to the field magnetism and to the armature current. Since the field winding and the armature are connected in series and, hence, the same current flows through each, the torque is roughly proportional to the square of the armature current.

Under a light load, the series motor takes but little current to produce the torque required and, hence, the resistance in series with the motor on starting is made large enough to allow only a small current to pass through the motor. The motor under these conditions speeds up rapidly and the greater the speed the more counter electromotive force induced and, hence, the less the current through the machine until the resistance is cut out. As shown with the shunt motor (See Experiment 14), to weaken the field increases the speed and, hence, the speed of an unloaded series motor becomes excessive and would damage the machine if allowed to run under this condition. The series motor must, therefore, always be connected to its load, as in street cars where the motor is geared or mechanically connected to the load. As a precaution, therefore, always see that a load is connected or coupled to the series motor before connecting it to the supply mains.

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Under load, the operation of the series motor is somewhat different from that of the shunt motor. For example, if the load on a series motor be doubled, the field current as well as the armature current is increased, so that the speed is reduced much more than in the shunt motor where the field current is practically constant at all loads. Again, if the armature current be doubled in a series motor, the torque is increased nearly four

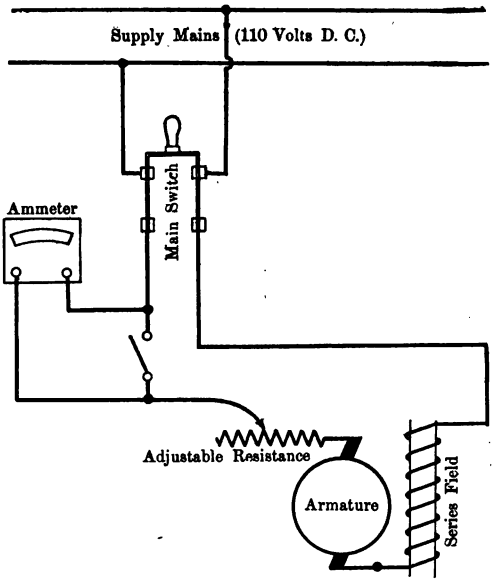

Fig. 16.—Series motor. The load, which must be connected to the motor throughout the experiment, is not shown in this diagram. The adjustable resistance represents the starting controller used with series motors.

times, since both armature and field current are doubled, while to double the armature current in the shunt motor merely doubles the torque (the shunt field current remaining constant).

Hence, under heavy loads, due to the fact that the large starting armature current flows through the series field in the series motor, it has a greater starting torque than the shunt motor where the field current remains sensibly constant irrespective of the value of the armature current.

The series motor is, therefore, well adapted to those cases where a large starting torque is desirable and where, under heavy loads,

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the speed should fall in order that the power requirements and, hence, the current may not be excessive as in street car operation. Where constant speed at all loads is a necessary requirement, the series motor is not adapted, as its speed variation between small and heavy loads is very large as compared with that of the shunt motor. Note that a given value of current through the series motor produces the same torque whatever the speed.

Current Supply.—110 or 220 volts Direct Current.

Apparatus Required.—(1) Series motor; (2) starting resistance, (some form of rheostat having a fairly large current carry-

Lever Arm =					
No.	Force at End of Brake Lever	Amperes	Volts	Speed	Shunt
1					Without Shunt Around Series Winding
2					
3					
4					
5					
6					With Shunt

Form 11.

ing capacity); (3) speed indicator; (4) brake to be used for loading the motor; (5) ammeter; and (6) voltmeter.

Order of Work.—1. Connect the motor to the supply mains as shown in Fig. 16, and arrange to have the brake permanently attached to the motor pulley throughout the experiment.

2. With the starting resistance all in, and the brake moderately tight, throw in the main switch and gradually increase the speed by cutting out the starting resistance. Tighten the brake until the current input equals ¼ more than the current rating on the name plate of the machine. Observe and record the torque (the tangential force at the rim of the pulley multiplied by the radius of the pulley), current, volts at terminals of motor, and speed. Use Form 11.

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3. Reduce the load until the input current equals the full load rating of the machine and repeat the observations of item 2.

4. Same for ¾, ½, and ¼ load current values in turn.

5. Place a low resistance around the series field terminals as a shunt. Operate the machine at its full load current value and observe the torque, current, volts and speed.

Written Report.—1. Explain briefly why the load must be permanently connected to a series motor.

2. Plot a curve using speed as ordinates and torque as abscissas from the observations of items 2, 3 and 4, *Order of Work.*

3. Explain the decrease in speed with increasing load as shown by this curve.

4. What changes were observed in the speed and torque in item 5 as compared with the corresponding observations in item 3, *Order of Work?* Explain.

5. A street car equipped with series motors, running at constant speed on the level, approaches an up grade. Explain the action of the motors in propelling the car up the grade, as regards speed, torque and current in-take, assuming that the motorman leaves the controller untouched.

6. Sometimes on climbing a steep grade a motorman throws the controller to the series notch. What is the "series notch", and why should this be an advantage under the circumstances?

EXPERIMENT 17.

Efficiency; Stray Power Test; Brake Test.

See Articles 155, 156 and 158 in the text book, also the *Theory* under Experiment 15 in the Manual.

Theory.—The losses in a generator or motor may be classed under the head either of losses which may readily be calculated, or of losses which are not subject to calculation. Thus the resistance losses (RI^2) may easily be calculated after measuring the resistance of field and armature, and from the currents involved. The friction losses in the bearings and at the brushes of the machine and in windage and the losses in the iron of the machine (usually called hysteresis and eddy current losses) cannot easily be calculated and are referred to as stray power loss. That is,

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the stray power loss includes all the losses in a generator or motor except the RI^2 or resistance losses, and is practically constant independent of the load.

A simple experiment to determine the stray power loss in a generator or motor is to drive the machine as an unloaded motor and to measure the power input under this condition. Obviously this input is all loss, since there is no useful power being delivered at the pulley. If, from this input at no load, the RI^2 losses in both field and armature be subtracted, the remainder represents the stray power loss in watts.

Inasmuch as the stray power loss is sensibly constant at all loads, the efficiency of a generator, for example, may be calculated when the stray power loss is known for any assumed load by the use of the equation for effiicency:

$$\text{Efficiency} = \frac{\text{Output}}{\text{Output} + \text{all losses}} = \frac{\text{Output}}{\text{Output} + \text{stray power loss} + RI^2 \text{ losses}}$$

Suppose, for example, it was desired to calculate the efficiency at half load. If the generator is rated at 10 kilowatts, and the stray power loss is found by experiment to be 500 watts, the efficiency may be calculated by a substitution in the equation as follows:

$$\text{Efficiency} = \frac{5000}{5000 + 500 + RI^2 \text{ loss in field and armature}}$$

The RI^2 loss in the field and armature are easily calculated from the resistance of the two windings, the terminal voltage and the armature current corresponding to the assumed load. Thus the R_1I^2 loss in the field is equal to $R_1 \times (E/R_1)^2$, and the RI^2 loss in the armature is the resistance of the winding (R_2) multiplied by the square of half the full load current as indicated on the name plate of the machine.

(Note: While the stray power loss varies slightly for different loads and speeds, it is treated as constant in this experiment for simplicity.)

Current Supply.—110 or 220 volts Direct Current.

Apparatus Required.—(1) Shunt machine; (2) starting box; (3) field rheostat; (4) speed indicator; (5) ammeter for the field

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circuit; (6) ammeter for the armature circuit; and (7) voltmeter.

Order of Work.—1. Connect the machine to the supply mains through the starting box, arranging an ammeter in both field and armature circuits.

2. Run the machine as a motor at normal speed and, with no load, observe and record the amperes to both field and armature and the volts at the motor terminals. (Note: Since the starting current of an unloaded motor is apt to be larger than its normal running current after starting, be sure to close the short circuiting switch about the armature ammeter before starting the motor. This makes possible the use of an instrument of low range for observing the rather small currents of the motor while in operation at no load.)

3. Record the full rated current and voltage of the machine as indicated on the name plate.

4. Shut down the machine and measure the resistance of the armature by the voltmeter-ammeter method as described in Experiment 2.

5. Arrange to load the machine by a brake, and observe and record the torque, speed, current in field and armature, and terminal volts at ¼, ½, ¾ and full rated load in turn.

Written Report.—1. From the observations in items 2 and 4, *Order of Work,* calculate the stray power loss, and the field and armature resistance of the machine used.

2. From item 5, *Order of Work,* calculate the output and input to the motor in watts, and calculate the efficiency of the motor by the brake method for these observations.

3. Calculate the efficiency of the motor for ¼, ½, ¾ and full load in turn by the stray power method, using the stray power loss as found in item 1, *Written Report,* and using the terminal volts and input current at full load as given on the name plate of the machine. Compare these calculations of efficiency with those found by direct measurement in item 2, *Written Report.*

4. Calculate the efficiency of the machine by the stray power method if run as a *generator* at full load, assuming the terminal volts and output current at full load to be the value given on the name plate of the machine.

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EXPERIMENT 18.

Static Torque Test on a Motor.

See Article 125 in the text book, also the *Theory* under Experiment 4 in the Manual.

The object of this experiment is to make a study of the torque of a motor in terms of the field and armature current, while the machine is at rest.

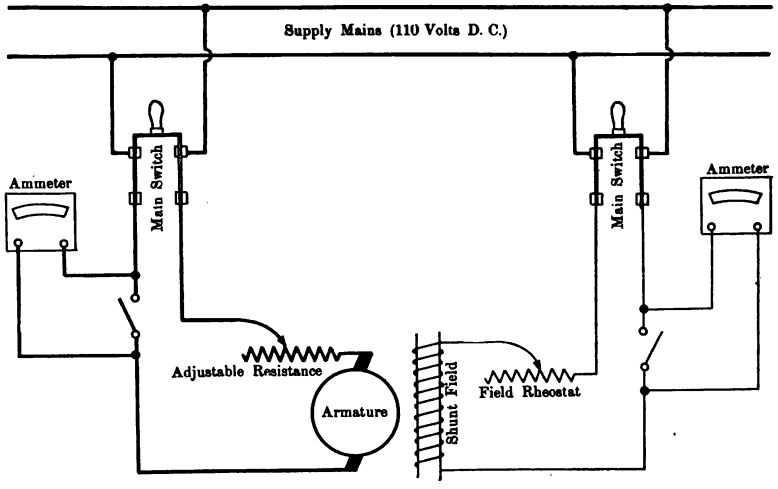

Fig. 17.—Study of the torque produced in an armature for various values of field and armature currents. Note that the currents in field and armature can be adjusted independently.

Theory.—The mechanical force which turns an electric motor is produced by the action of the magnetic field on the current in the armature conductors. The simplicity of the elements which produce motion in the motor are sometimes lost sight of on account of the conditions which determine the armature current, such as load, speed and the like. In this experiment, these secondary conditions are eliminated by taking the observations on the motor when at rest, and the definite relation of field and armature current to the torque produced is thus emphasized.

The magnetic field is not directly proportional to the current which produces it, because as the field magnets become saturated, the magnetism ceases to increase in direct proportion to the cur-

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rent (see Article 98 in the text book). Hence, in this experiment, if the torque is not found to vary directly with the field current throughout the observations, it must be remembered that the torque *is* varying directly with the magnetic field, but the field is not varying directly with the field current due to saturation of the iron. Obviously the saturation effect will not be very noticeable for small values of the field current.

Current Supply.—110 or 220 volts Direct Current.

Apparatus Required.—(1) Shunt motor; (2) resistances for both field and armature circuits; (3) Prony brake; (4) ammeter for field circuit; (5) ammeter for armature circuit; and (6) voltmeter.

Order of Work.—1. Connect the field winding through a field rheostat, which should possess a wide range of adjustment, to the supply mains; also, the armature through a suitable rheostat to the supply mains; each to have its own switch as shown in Fig. 17.

2. Clamp the brake tightly to the pulley of the motor and with all the field and armature resistance cut in, throw in first the field and then the armature switch. See that the torque acts against the opposition of the brake, and that the armature does not rotate.

3. With a constant field current, that is, with normal volts across the field terminals, adjust the armature current to ¼ full load value and observe and record the field and armature current and the torque produced.

4. Same as 3, using ½, ¾, full load and 1¼ load currents through the armature in turn.

5. With, say, full load armature current, reduce the field current to ½ its normal value, and observe and record the field and armature currents and the torque produced.

6. Keeping the armature current constant, repeat the observations of item 5 for ¾, normal and 1¼ normal values of the field current.

7. Maintaining constant field current and constant torque, decrease the resistance in series with the armature and allow the motor to run. Find and record the relation between armature current and torque for a number of different speeds; also the relation between the speed and the volts across the armature terminals for each of these values of speed.

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Written Report.—1. From the observations in items 3 and 4, *Order of Work,* how does the torque (or mechanical force) at the pulley vary with the armature current for a constant value of field current?

2. From items 5 and 6, *Order of Work,* how does the torque vary with the field current for a constant value of armature current?

3. If the torque did not vary directly with the field current in the experiment, to what is such irregularity due?

4. From the general observations of this experiment, explain why a shunt motor must slow down when an added load is thrown on its pulley if it is to carry this added load?

5. From item 7, *Order of Work,* what is the relation between armature current and torque at different speeds; and what is the relation between speed and volts across the armature in each of these cases? Explain briefly.

EXPERIMENT 19.

Shunt Generators in Parallel.

The object of this experiment is to observe the factors which enter into the operation of shunt generators in parallel, first, as regards the necessary conditions for throwing one generator in parallel with another machine, and second, as to the items which are involved in the equal or proportionate sharing of the total output of a power station by the various generators connected in parallel for supplying this total output.

Theory.—In many electric stations it is the practice to supply power from bus bars to which are connected a number of generators, each delivering its share of the total load supplied from the common bus bars. In this way, when the load requirements are low, say during the day in a lighting station, a few of the generators may be operated at or near full load and, hence, at high efficiency, and as the total output of the station increases, one after another of the remaining machines may be connected to the bus bars in parallel with those already in operation. Obviously the positive terminal of each machine must be connected to the positive terminal of the bus bars.

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If before connecting a machine to the bus bars its voltage is just equal to that of the bus bars, no current will flow. If the voltage induced in the armature be slightly higher, a current will flow. Suppose the machine, when carrying no load, has a voltage 3 per cent. higher than the bus bars and that before it is connected to the bus bars it is loaded until the terminal electromotive force decreases (due principally to the *RI* drop in the armature) and becomes equal to that on the bus bars. If now the load be thrown off quickly and the machine be connected to the bus bars, it is in condition to continue delivering the same current to the bus bars that it formerly delivered to its independent load.

Hence, if the bus bar voltage be much below that of the voltage induced in the armature connected to it, the current supplied by the armature will rise when the two are connected, until the volts (*RI*) drop in its armature winding and the leads from the armature terminals to the bus bars equals the difference between the bus bar and the induced armature voltage. If this difference be zero, no current will flow from the machine; while if the difference be such that the accompanying *RI* drop in the leads and armature involves a current greater than normal for the machine, the generator will, of course, be overloaded.

As the induced voltage of a generator depends on the field magnet strength for constant speed conditions, the load may be increased or decreased on a given machine connected in parallel with others, by the simple variation of its field rheostat resistance, assuming that the driving engine delivers a corresponding increased or decreased load.

Where two similar machines of the same capacity are arranged for parallel operation, the output from each should equal one-half of the total power supplied by the bus bars. If it should be desirable, however, to reduce the load on one of the machines and yet maintain the total output constant at a constant bus bar voltage, it would be necessary to increase the field resistance of the one generator to lower its part of the total load, and to reduce the field resistance of the other generator to increase its part of the total load, thus maintaining the voltage and the total output at a constant value. In this way the total load may be shifted from one machine to another.

Since the terminal voltage of a shunt generator varies with the load (see Experiment 9), and further, since this change of volt-

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age with load is not apt to be exactly the same with any two machines, even after two or more shunt generators are adjusted to give their share of the total load, they may not continue to share the total load in this exact proportion for all bus bar or total loads, on account of this variation in the voltage changes for different machines. This will give rise to slight fluctuations in the sharing of the loads, which, if sufficiently noticeable, can be offset by hand regulation of the field rheostats when necessary.

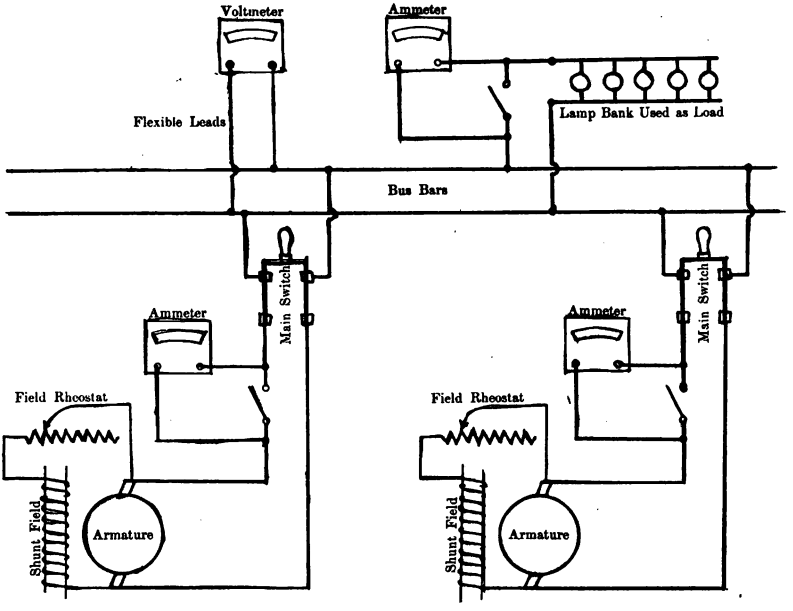

Fig. 18.—Study of the parallel operation of shunt generators. A voltmeter, not shown in the diagram, is to be available for measuring the voltage of the individual machines.

Current Supply.—From the Shunt Generators assigned.

Apparatus Required.—(1) Two shunt generators; (2) lamp banks to be used as a common load supplied from bus bars; (3) field rheostats for each machine; (4) a double-pole single-throw switch for each machine and for the total load (3 in all); (5) three ammeters, one for each machine and one for the total output current from the bus bars; (6) two voltmeters, one for the bus bars and one for the on-coming machine.

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Order of Work.—1. Arrange the connections of the two assigned shunt generators as shown in Fig. 18.

2. With all switches open, start up the two generators and adjust the voltage of each to its normal value.

3. Connect one of the generators ("A") to the bus bars (two lengths of wire) and turn on enough lamps to load the machine to its full capacity.

4. Adjust the voltage of the other generator ("B") to the same value as the bus bar voltage and connect it to the bus bars, being sure that the positive terminal of the machine is connected to the positive terminal of the bus bars.

5. Vary the field rheostat of machine "B" until the current in the two machines has the same value, at the same time adjusting the field rheostat of machine "A" so that the bus bar voltage remains constant. Then turn on enough lamps to load each of the machines to its full rated capacity.

6. With both machines fully loaded, observe and record the bus bar voltage, current delivered by each machine and total current taken from the bus bars.

7. Leaving the field rheostats untouched, repeat the observations of item 6 for ¾, ½ and ¼ of the total load current and for zero current from the bus bars in turn.

8. Turn on the lamps and vary the field rheostats and lamps until each machine delivers one-half of its rated load. Adjust the field rheostat of the two machines until the machine "B" is delivering all the current and machine "A" is unloaded, maintaining constant voltage at the bus bars throughout this adjustment. Now disconnect machine "A" from the bus bars.

Written Report.—1. What would be the result if the negative terminal of machine "B" was connected by mistake to the positive terminal of the bus bars in item 4, *Order of Work?*

2. From the observations in items 6 and 7, in which of the two machines is the armature voltage reduced the more as the total load is decreased?

3. In item 8, why must all the load be shifted to machine "B" before machine "A" is disconnected from the bus bars?

4. What would have been the result if in item 4, *Order of Work,* machine "B" had been connected to the bus bars when

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its induced voltage was much above that of the bus bars? If it was lower?

5. Explain any inequalities observed in the sharing of the total bus bar load by the two machines as the total output was reduced in item 7. If any inequalities existed, to what were they due? Explain.

EXPERIMENT 20.

Compound Generators in Parallel.

See Article 122 in the text book, also the *Theory* under Experiment 19 in the Manual.

The object of this experiment is to observe the factors involved in the parallel operation of compound generators, first, in regard to the conditions necessary before throwing one generator in parallel with another machine, and second, in regard to the items which influence the equal or proportionate sharing of the total output of a power station by the various generators connected in parallel for supplying this total station output.

Theory.—As stated in experiment 19, the general practice in electric stations is to supply power from bus bars to which are connected a number of generators in parallel with each other, each delivering its share of the toal load supplied from the common bus bars. In this way it is possible to operate the machines at a relatively high efficiency even when the station output is low, by disconnecting certain machines and thus keeping the remaining machines in operation at or near full load. In practice the generators thus used are compound wound machines.

As in the parallel operation of shunt generators, where the current delivered by a given machine depends on the difference between its induced voltage and the bus bar voltage, so in the parallel operation of compound generators the difference between the induced voltage in a given machine and the bus bar voltage determines the amount of current supplied by the machine. The induced voltage in a shunt generator depends primarily on the field strength and on the speed of the machine. In the compound generator, however, the induced voltage depends not only on the field strength produced by the shunt winding and on the speed,

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but also on the additional field produced by the series winding. Hence, the equal or proportionate sharing of the load with compound generators depends on an additional factor, namely, the strength of the field magnetism produced by the series field current.

If two compound generators are connected in parallel (in general as shown in Fig. 19, except that a series winding is inserted between the upper armature terminal and the machine ammeter in each case), each machine may be made to deliver its share of a given total bus bar load by adjusting its shunt field rheostat. If the machines are over-compounded, however, and one machine speeds up due to an increase in the speed of its driving engine, this means an increase in the induced voltage (due to the increase in speed). The output of this machine is then increased (meaning, of course, that the output of the second machine falls off by a corresponding amount) and the action of the series winding is to increase still further the induced voltage in the first machine. This condition being cumulative, results in an excessive overload for the first machine and obviously in an unbalanced condition of operation. (This effect of instability is more noticeable with over-compounded than with flat or under-compounded generators.)

To prevent this unstable condition an equalizer connection is made between the two machines, at the junction of the series winding and the armature terminal in each case (for the short shunt connection), and this places the two series windings in parallel with each other as regards the output current from the machines, thus insuring that the series field current will be inversely proportional to the resistance of the windings at all times, irrespective of any tendency for the armature currents to be unequal.

If the compounding of the machines is different, thus causing an unequal sharing of a given total bus bar load, the resistance of the series field circuit must be changed by connecting an auxiliary resistance in series with the series winding, thus reducing the part of the total current which flows through the series winding of the first machine and allowing more current to flow through the series winding of the second machine.

Adjustments of the compounding by means of a shunt around the series field, as explained in Experiment 11, will not serve the

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purpose in this case on account of the parallel condition of the two series windings. (Note: The student should make a diagram, similar to Fig. 19, on the data sheet with the series fields arranged for the short shunt connection, and verify, theoretically, the instability of operation without an equalizer connection. Also, with an equalizer connection on the diagram, the statements in the two preceding paragraphs should be verified before the experiment is undertaken.)

Current Supply.—From the Compound Generators assigned.

Apparatus Required.—(1) Two compound generators (preferably over-compounded); (2) lamp banks to be used as a common load supplied from the bus bars; (3) field rheostats for each machine; (4) a double-pole single-throw switch for each machine and for the total load (3 in all); (5) ammeters, one for each machine, one for the total output current from the bus bars, and one to be connected in the equalizer circuit between the two machines (the latter instrument preferably a double-throw ammeter to indicate the current no matter in which direction it flows); (6) two voltmeters, one for the bus bars and one for the on-coming machine; (7) equalizer connection (a wire to be connected between the two machines at the junction of the series field and the armature in each case, where the short shunt connection is used).

Order of Work.—1. Arrange the connections of the two assigned compound generators similar to Fig. 19, except that the series field is to be connected between the upper armature terminal and the ammeter in each case, and the equalizer is to be connected between the upper armature terminals of the two machines through an ammeter.

2. With all switches open, start the two generators and adjust the voltage of each to its normal value.

3. Connect one of the generators ("A") to the bus bars (two lengths of wire) and turn on enough lamps to load the machine to its full capacity.

4. Adjust the voltage of the other generator ("B") to the same value as the bus bar voltage (or a trifle lower) and connect it to the bus bars, being sure that the positive terminal of the machine is connected to the positive terminal of the bus bars. (Remember that as soon as machine "B" is thrown on to the bus bars, a current will flow through its series field from machine

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"A" which will tend to increase the induced voltage in the armature of "B". This is the reason for adjusting the voltage of "B" a trifle lower than the bus bar voltage before connecting the two. Watch the ammeter of machine "B" carefully until the adjustments of load have been made according to the following item.)

5. Vary the shunt field rheostat of machine "B" until the current of the two machines is the same in value, at the same time adjusting the shunt field rheostat of machine "A" so that the bus bar voltage remains constant. Then turn on enough lamps to load each machine to its full rated capacity.

6. With both machines fully loaded, observe and record the bus bar voltage, current delivered by each machine, total current taken from the bus bars, and the equalizer current (noting in which direction the equalizer current flows, that is, whether from machine "A" to "B", or from "B" to "A".)

7. With the field rheostats untouched, repeat the observations called for in item 6, for ¾, ½, and ¼ of the total load, and for zero current from the bus bars in turn.

8. Turn on the lamps and vary the field rheostats and lamps until each machine delivers one-half of its rated load. Adjust the field rheostat of the two machines until machine "B" is delivering all the current and machine "A" is unloaded, maintaining constant voltage at the bus bars throughout the adjustment. Now disconnect machine "A" from the bus bars.

9. Same as items 6 and 7, with a resistance inserted in one of the series field circuits, so that when the load from the bus bars equals the total rated capacity of the two machines combined, machine "A" is delivering 1¼ of its rated capacity and machine "B" ¾ of its rated capacity.

Written Report.—1. Explain why the operation of compound generators in parallel is unstable without an equalizer connection.

2. Why is this unstable condition less noticeable for flat and under-compounded than for over-compounded machines?

3. What current was indicated by the equalizer circuit ammeter in items 5, 6 and 7, *Order of Work*? If any, to what was it due?

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4. Explain any inequalities observed in the sharing of the total bus bar load by the two machines, as the total output was reduced in items 6, 7 and 9. If inequalities existed, to what were they due? Explain.

5. Explain the use of resistance in series with one of the series field windings in item 9. How did it affect the proportionate sharing of the total output by the two machines as the total output was reduced?

6. Why cannot a shunt around the series field be used for the purpose of adjusting the sharing of the total output in item 9 instead of a resistance in series with the series field winding? What is the function of the resistance as here used? Explain.

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Experiments 21 to 30, inclusive, constitute the Alternating Current portion of the Manual.

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ALTERNATING CURRENT

EXPERIMENT 21.

Resistance and Reactance in Series.

See Articles 261, 269, 270, 271, 272, 277, 278 and 279 in the text book.

The object of this experiment is to make a study of the voltage, current and power relations in a simple alternating current circuit containing both resistance and reactance in series.

Theory.—Ohm's law states that in a circuit, or portion of a complete circuit, where all the voltage goes to overcome resistance only, the current (I) equals E/R, where E is the electromotive force across the terminals of the circuit and R is the resistance of the circuit in ohms. This law holds true for both direct and alternating current circuits as regards that portion of E which overcomes resistance (R) only.

In a direct current motor, the voltage (E_1) across the terminals of the armature is partly used to overcome resistance and partly to overcome the counter electromotive force induced in the armature by the rotation of the armature wires in the magnetic field, that is, E_1 (the impressed electromotive force) $=RI+E_2$ (the counter electromotive force of the armature). Note that the RI drop and E_2 are added numerically.

In an alternating current circuit consisting of a coil of wire, the voltage (E_1) across the terminals of the coil is partly used to overcome resistance and partly to overcome the counter electromotive force induced in the coil by the rapid reversals of the magnetic field in the coil due to the alternating current, that is, E_1 (the impressed electromotive force)$=RI$ added vectorially to E_2 (the counter electromotive force in the coil). Note that the RI drop and E_2 are added vectorially (not numerically) because they are 90° apart in phase. E_2, the counter electromotive force, is usually expressed as XI, that is, the reactance (X) of the cir-

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cuit times the current (I), X being the opposition due to the inductance of the coil, but for convenience expressed in ohms like the resistance R. (Read carefully Articles 165 and 171 in the text book.)

Since the reactance of a circuit depends on the frequency of the alternating electromotive force across its terminals, the opposition due to reactance is high for high frequencies and low for low frequencies in a given circuit. Obviously the frequency has nothing whatever to do with the RI drop in a circuit. Hence, if an alternating current of 10 amperes flows in a circuit containing both R and X when 110 volts at 60 cycles are applied at its terminals, if the frequency is reduced to 30 cycles, and the current maintained at 10 amperes by reducing the electromotive force, the RI component of E will, of course, remain the same, while the XI component will be ½ as great as before because X is ½ its former value. A coil containing both resistance and reactance produces the same result as a separate resistance and a separate reactance connected in series.

Since the voltage required to overcome R and X is made up of two components 90° apart in phase, the combined effect of the two (R and X) may be expressed as Z, which equals the square root of (R^2+X^2). Z (expressed in ohms) is usually termed the impedance of the circuit, and it represents the total opposition to the flow of current in an alternating current circuit due both to resistance and to counter electromotive force (or reactance).

In a direct current circuit containing several resistances in series when a current (I) flows, the volts drop across the various resistances added together *numerically* determine the total voltage of the circuit. Similarly, in an alternating current circuit, containing both resistance (R) and reactance (X) in series, the volts drop across the various resistances and reactances are added *vectorially* to determine the total voltage of the circuit.

In the direct current circuit the power in the circuit equals the electromotive force (E) times the current (I) because both E and I may be thought of as in the same direction at all times. In the alternating current circuit, the power in the circuit also equals EI in those cases where E and I are in the same direction at all times (that is, in phase with each other), as in a circuit containing resistance only. Where E and I are not in the same direction at all times, (that is, out of phase) as in circuits con-

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taining reactance as well as resistance, account must be taken of the fact that E and I are out of phase by an angle "a", and the product EI must be multiplied by a factor called the power factor ($\cos a$) of the circuit. A wattmeter, however, indicates the true power ($EI \cos a$) at all times, even in those cases where the voltmeter reading (E) and the ammeter reading (I) taken together do not indicate the true power.

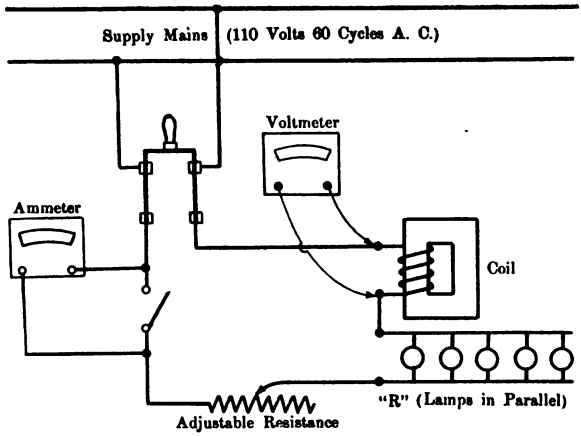

Fig. 19.—Study of the voltage and current relations in series circuits, made up, in this case, of a reactance coil and a lamp bank in series. The adjustable resistance shown to the left is an auxiliary to the apparatus under test.

In a circuit like that of Fig. 19, where a coil, with both resistance and reactance is connected in series with a resistance (lamp bank), the current (I) is obviously the same throughout the circuit and the voltage E_s across the entire circuit is equal to the RI drop (E_1) across the lamps added vectorially to the voltage (E_2) across the coil. The relation of these 3 voltages, each of which may be measured separately by a voltmeter, is shown in Fig. 20. This diagram also shows graphically how the reactance (X) of the coil may be determined from the voltage readings.

Current Supply.—110 volts 50 and 60 cycle Alternating Current and 110 volts Direct Current.

Apparatus Required.—(1) Reactance coil; (2) circuit containing resistance only, for example, a lamp bank; (3) voltmeter

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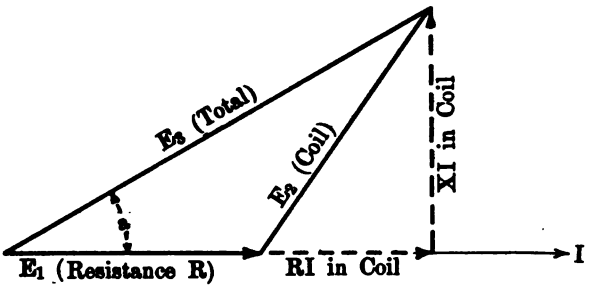
with rather large range; (4) voltmeter with low range (for measuring the *RI* drop when *Direct Current* is used); (5) ammeter; and (6) wattmeter.

Order of Work.—1. Connect the coil and the resistance (R) in series as shown in Fig. 19 (the auxiliary resistance is put in to permit of current adjustments). Adjust the auxiliary resistance until a fair value of current flows from the 110-volt, 60-cycle Alternating Current mains. Keeping this current constant,



a = Phase Difference Between E_s and I

Fig. 20.—Vector relations of the voltages and current in series circuits, as in Fig. 19.

observe and record the volts across the coil, across the resistance (R), the total volts, not including the auxiliary resistance, current, frequency, and total watts, not including the auxiliary resistance. Use Form 12.

2. Connect the same coil and resistance (R) to the 110-volt Direct Current mains, and reduce the voltage across the coil and resistance (R) by the auxiliary resistance until the current is the same value as in item 1. Observe and record the same readings called for in item 1.

3. Same as item 1, except that R is to have 1 2/3, 1 1/3, 2/3 and then 1/3 the original value in turn, adjust to the same current as in item 1 in each case, and repeat the observations called for in item 1.

4. Connect the coil and the resistance (R) as in item 1 to 50 (or less) cycle Alternating Current mains and adjust the current

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until it is the same value as in items 1 and 2. Take the same observations called for in item 1.

Written Report.—1. From the observations in item 1, *Order of Work,* draw a diagram similar to Fig. 20, and from this determine graphically the reactance volts (XI) drop of the coil and the phase difference between E_s and I in degrees; also calculate the reactance (X) in ohms and the power factor of the entire circuit not including the auxiliary resistance. The power factor= watts (indicated by wattmeter) $/E_sI$, that is, true watts divided by apparent watts.

No.	Supply Current	Volts			Amperes	Frequency	Watts (Total)
		"R"	Coil	Total			
1	(A. C.)						
2	(D. C.)						
3	(A. C.)						

Form 12.

2. Is E_sI in item 2, *Order of Work,* the same in value as the wattmeter reading in item 1, *Order of Work,* for the same value of current (I) in each case? If so, why? If not, why?

3. Draw a vector diagram, similar to Fig. 20, for the voltages observed in items 3 and 4, *Order of Work,* and repeat the requirements under 1, *Written Report.*

4. How do the reactance volts drop in items 1 and 4, *Order of Work,* compare?

(Note: The impedance of an alternating current circuit often involves reactance due to capacity as well as to inductance, but for simplicity this experiment has been limited to the effect due to resistance and inductive reactance only.)

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EXPERIMENT 22.

Resistance and Reactance in Parallel.

See Article 273 in the text book, also the *Theory* under Experiment 21 in the Manual.

The object of this experiment is to make a study of the voltage, current and power relations in a simple alternating current circuit containing both resistance and reactance in parallel.

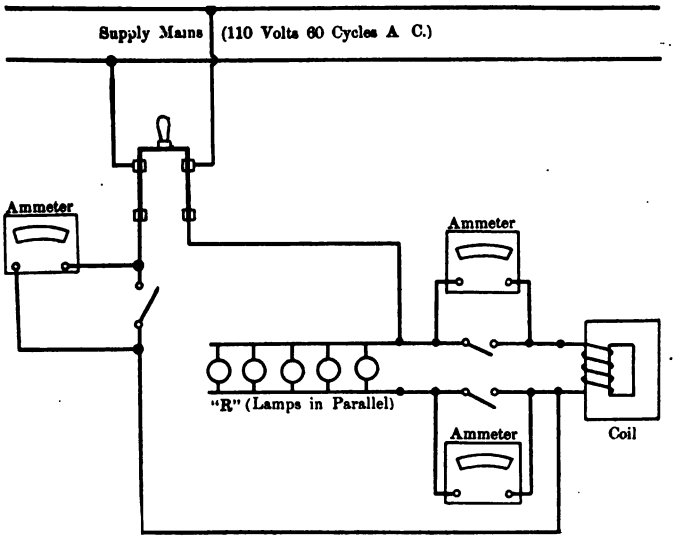

Fig. 21.—Study of the current and voltage relations in parallel circuits, made up, in this case, of a reactance coil and a lamp bank. Note that the two ammeters to the right measure the current in the coil and in the lamp bank, respectively.

Theory.—In direct current circuits where a number of resistances are connected in series, the current is the same throughout the circuit, while the volts drop across the separate resistances are added numerically to determine the total voltage of the circuit. In the alternating current circuit, where resistances and reactances are connected in series the current is also obviously the same throughout the circuit, while the volts drop across the various parts of the circuit are added vectorially to determine

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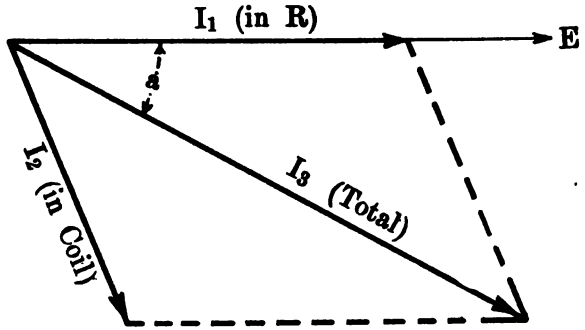
the total voltage. These have been investigated in experiment 21.

In direct current circuits where a number of resistances are connected in parallel, the voltage is obviously the same across each of the resistances, while the total current is equal to the numerical sum of the individual currents in the various resistances. In the alternating current circuit, where resistances and reactances are connected in parallel, the voltage is the same across the terminals of each portion of the circuit, while the total current is equal to the vector sum of the individual currents through the separate parts of the circuit.



a = Phase Difference Between E and I_3

Fig. 22.—Vector relations of the currents and voltage in parallel circuits, as in Fig. 21.

In a circuit like that of Fig. 21, where a coil with both resistance and reactance is connected in parallel with a resistance (lamp bank), the voltage (E) is the same for both parts of the circuit, and the total current (I_3) is equal to the current I_2 in the coil added vectorially to the current I_1 in the lamp bank. The diagram shown in Fig. 22 indicates the relations of these three currents, each of which may be measured separately by an ammeter. From this diagram the phase difference between I_1, I_2 and I_3 may be determined graphically.

Current Supply.—110 volts 50 and 60 cycle Alternating Current and 110 volts Direct Current.

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Apparatus Required.—(1) Reactance coil; (2) circuit containing resistance only (lamp bank); (3) ammeters, one for each circuit and one for the total current; (4) voltmeter; and (5) wattmeter.

Order of Work.—1. Connect the coil and the lamp bank in parallel to the 60-cycle mains, as shown in Fig. 21, with due care that the current through the coil is not excessive. Observe and record the current in the coil, in the lamp bank and the total current, volts, frequency and total watts.

2. Connect the coil and lamp bank to the 110-volt Direct Current mains, adjusting the voltage if necessary to the same value as used in item 1. Observe and record the same readings called for in item 1. (Note: If the current through the coil is excessive with the Direct Current, insert a protective resistance in series with it to bring down the current to a normal value, and repeat item 1 with this extra resistance in circuit so as to have the voltage conditions the same in both items 1 and 2.)

3. Same as item 1, except that R is to have 1 1/3 and 2/3 the original value in turn, use the same voltage as in item 1 in each case, and repeat the observations called for in item 1.

4. Same as item 1, except that a reactance coil with a different power factor from the original coil is to be substituted for the lamp bank. Use the same voltage as in item 1, and repeat the observations called for in item 1.

5. Connect the coil and the lamp bank to the 50-cycle mains, and adjust the voltage to the same value as in items 1 and 2. Take the same observations called for in item 1.

Written Report.—1. From the observations in item 1, *Order of Work,* draw a diagram similar to Fig. 22, and from this determine graphically the phase difference between E and I_3 in degrees and calculate the power factor of the entire circuit (true watts divided by apparent watts).

2. Does EI_1 (Direct Current) equal EI_1 (Alternating Current) in items 1 and 2, *Order of Work?* If so, why? If not, why?

3. Same as item 1, *Written Report,* for items 3 and 4, *Order of Work.*

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4. Draw a vector diagram similar to Fig. 22 for the current values observed in item 5, *Order of Work,* and repeat the requirements called for under item 1, *Written Report.*

5. How do the current values through the coil compare in items 1, 3 and 5, *Order of Work?*

6. Does EI_3 in item 2, *Order of Work,* equal the wattmeter reading in item 1, *Order of Work?* If so, why? If not, why?

(Note: The impedance of an alternating current circuit often involves reactance due to capacity as well as to inductance, but for simplicity this experiment has been limited to the effect due to resistance and inductive reactance only.)

EXPERIMENT 23.

Study of Three-Phase Circuits.

See Article 282 in the text book.

The object of this experiment is to afford an opportunity for observing the voltage and current relations in three-phase circuits. (Note: Two-phase circuits are somewhat simpler and the relations between phases perhaps more readily understood, hence, where the laboratory apparatus is two-phase, the following experiment may be carried out with the two-phase instead of the three-phase apparatus as here suggested.)

Theory.—As three-phase alternating current transmission of electric power is very generally used over long distances, and further, since many three-phase induction motors are in service, the general relations of voltage and current in such circuits are of special interest.

A single winding on the armature of an alternating current generator with two collector rings for delivering the current, is called a single-phase machine. Two electrically separate windings may be used instead of one, each winding terminating in a set of two collector rings and thus making a two-phase machine. The two windings in such a case are wound with a definite angular displacement between corresponding wires, this displacement being such that the electromotive forces in the two coils differ by 90° in phase. Similarly, three electrically separate coils may be wound on the armature for making a three-phase generator,

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the displacement of the wires of the three windings being such that the electromotive forces differ in phase by 120° from each other.

The principal advantages of the three-phase as compared with the single-phase current are first, the economy in the amount of copper wire required for the transmission of a given amount of power by the three-phase scheme, and second, the improved con-

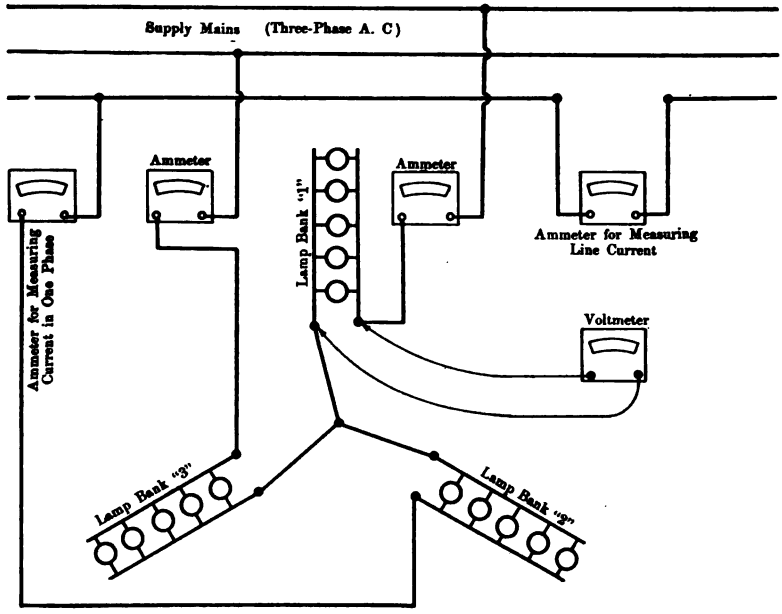

Fig. 23.—Study of the voltage and current relations in a three-phase "Y" (or Star) connected receiving circuit.

ditions afforded by three-phase currents in the operation of induction motors, and other apparatus.

The six terminals of a three-phase armature may either be connected for the so-called *Y* (or Star) or the Delta connection, and similarly the three component parts of the receiving circuit for the three-phase line may either be connected for *Y* or for Delta operation.

From Fig. 406, page 512 of the text book, showing a *Y* connected system, it can readily be seen that the electromotive force between any two of the outside line wires, *X*, *Y* and *Z* (the wire

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connected to the middle point is generally omitted in practice) is the vector sum of the electromotive forces induced in the two coils connected in series between these two line wires. Further, as the electromotive forces in series are 60° apart in phase, the vector sum of the two is equal to the $\sqrt{3}$ (=1.73) times that in one, since the electromotive forces are the same in each of the three armature coils, and as explained in the text book. The cur-

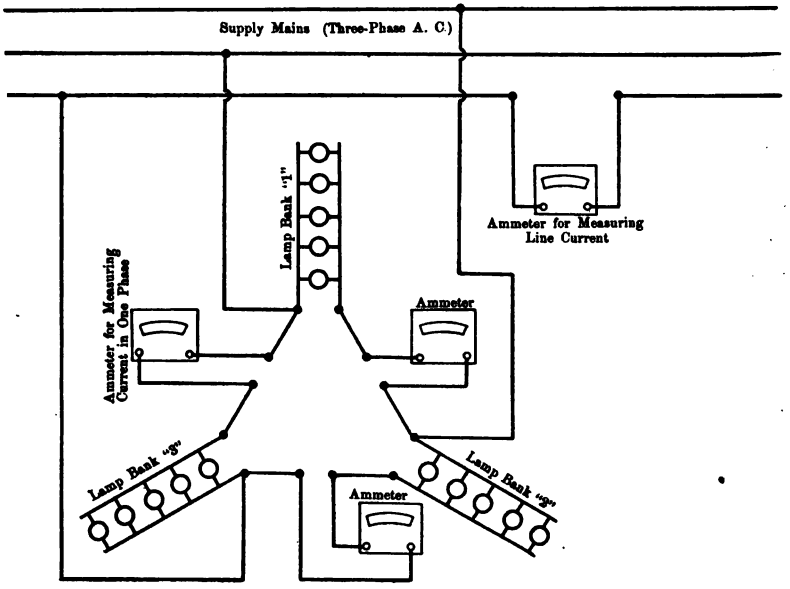

Fig. 24.—Study of the voltage and current relations in a three-phase "Delta" connected receiving circuit.

rent in any one of the outside line wires, however, is supplied by one armature coil only, as will be seen by an inspection of the illustration. Hence, the current in the line wire and in the armature coil to which it is connected, is the same in value.

From Fig. 408, page 513 of the text book, showing a Delta connected system, it will be seen that the electromotive force between any two of the line wires, *X*, *Y* and *Z*, is equal to the electromotive force induced in the armature coil, shown in the upper part of the figure, connected between the terminals of the two line wires. Further, since any one of the line wires receives current

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from the two coils terminating at its connection to the armature circuit, the current in any one line wire is the vector sum of the currents in the two coils or the $\sqrt{3}$ times the current in one coil (since the current has the same value in each of the three armature coils).

Hence, if E and I be the voltage and current respectively in a single armature coil of a Y connected generator, the voltage between any two line wires is $\sqrt{3}E$, while the current per line is simply I. With a Delta connection, this same machine would produce a voltage E between any two line wires and a current per line equal to $\sqrt{3}I$. Thus a given number of turns on the armature of a three-phase generator results in a higher line volt-

No	Connection Used	Amperes				Volts			
		Lamp Bank "1"	Lamp Bank "2"	Lamp Bank "3"	Line	Lamp Bank "1"	Lamp Bank "2"	Lamp Bank "3"	Line
1	"Y"								
2	"Y"								
3	"Delta"								

Form 13.

age if Y than if Delta connected. Note that the total power is the same for the given machine no matter which way it is connected, since it is expressed by $\sqrt{3}EI$ in each case (assuming unity power factor).

Current Supply.—Three-phase Alternating Current.

Apparatus Required.—(1) Three similar receiving circuits (lamp banks); (2) four ammeters, one for each receiving circuit and one for a single line; (3) voltmeter.

Order of Work.—1. Arrange the three lamp banks as a Y connected receiving circuit to be supplied by a three-phase generator as shown in Fig. 23. Adjust the current so as to be equal in each of the three lamp banks, and observe and record the current in each of the three lamp banks and in one of the lines, also the voltage between any two line wires and across each of the three lamp banks. Use Form 13.

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2. Same, for twice the current value in each of the lamp banks.

3. Arrange the three lamp banks as a Delta connected receiving circuit, as shown in Fig. 24, and repeat the observations called for in items 1 and 2.

4. Ascertain whether the generator armature windings are connected *Y* or Delta.

5. Observe the number of terminals in one of the three-phase induction motors in the laboratory.

Written Report.—1. From the observations in items 1 and 2, *Order of Work,* calculate the numerical relation between line and individual receiving circuit voltage and current. Record these calculations in the Form on the data sheet.

2. Same, for item 3, *Order of Work.*

3. When the armature terminals of a three-phase generator are arranged for the *Y* connection, where are the connections made in the machine? Explain.

4. Same, for Delta connected armature winding. Explain.

5. In Fig. 406, page 512 of the text book, a fourth wire is shown tapped to the common intersection of each of the *Y* connected armature windings. Why can this fourth wire usually be omitted in practical cases?

6. In the three-phase Delta connected armature winding, why is it that there is no circulation of current about the three windings which are in reality connected in series as a closed loop?

7. Why is the current per line in a Delta connected circuit equal to the $\sqrt{3}$ times the current in one armature winding?

EXPERIMENT 24.

Study of the Transformer.

See pages 268, 269, 270, 271 and Articles 161, 164 and 165 in the text book.

The object of this experiment is a study of the principles of construction and operation of the transformer.

Theory.—If two electrically separate coils of wire be wound on the same iron core, one of which is connected to alternating current supply mains, the rapid reversals of magnetism produced by the alternating current in the one coil (the primary) set up

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an induced alternating electromotive force in the other coil (the secondary).

The reversals of magnetism induce an electromotive force in the primary as well as in the secondary, and this induced electromotive force (sometimes called counter electromotive force) opposes the impressed electromotive force, thus keeping the primary current down to a low value when no current is being delivered by the secondary coil. If the second coil delivers current to lamps, the magnetic field produced by it passes through the primary coil and the counter electromotive force of the primary coil is reduced, thus permitting the necessary increase in primary current to maintain the load on the secondary. Note that the

No.	Primary				Secondary			
	No of Coils	Series or Parallel	E_1	I_1	No. of Coils	Series or Parallel	E_2	I_2
1								
2								
3								

Form 14.

primary current, with no load on the secondary, is merely that required to magnetize the iron core.

Since the magnetic field in the primary coil is roughly proportional to the number of turns of wire for a given current, and since the electromotive force induced in the secondary coil by the given rapidly changing magnetic field is proportional to the number of turns of wire in the coil, the induced electromotive force in the secondary winding (E_2) is related to the impressed electromotive force (E_1) in the primary directly as the number of turns of wire in the two coils. Obviously the power delivered by the secondary winding (E_2I_2) is equal to the power received by the primary winding (E_1I_1) (ignoring the slight losses in the transformer), hence, the current in the secondary (I_2) is related to the current in the primary (I_1) inversely as the number of turns of wire in the two coils.

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Current Supply.—110 volts Alternating Current.

Apparatus Required.—(1) An iron core with a permanently wound fine wire coil in four equal parts with taps to be used as a primary, and four rather coarse insulated wire coils, to be used as a secondary, wound with the same number of turns each as the primary coils, and with taps; (2) an uninsulated copper ring to fit loosely over a reactance coil with an iron core; (3) two ammeters; and (4) voltmeter.

Order of Work.—1. Using one of the heavy wire coils, connect one of the primary coils to the supply mains, and observe and record the number of turns in each coil, the primary volts (E_1), and secondary volts (E_2). Use Form 14.

2. Same, with 2, 3 and 4 primary coils in series, in turn.

3. With the four primary coils in series, use two of the secondary coils in series and repeat the observations called for in item 1.

4. Same, for 3 and 4 secondary coils in series, in turn.

5. With the four primary coils in series and one of the secondary coils, connect the secondary terminals to a lamp bank and observe and record E_1, E_2, I_1 and I_2.

6. Same, using 2, 3, and 4 secondary coils in series and 2 and 4 secondary coils in parallel, in turn.

7. With the reactance coil connected to the supply mains, place the copper ring over the iron core, holding it with a pair of pliers.

8. Inspect the windings, the iron core and the case of a commercial transformer, making a rough sketch with dimensions.

Written Report.—1. Calculate the relation of primary to secondary turns, and E_1 to E_2 in item 1, *Order of Work.* Explain.

2. Same, for items 2, 3 and 4, *Order of Work.* Explain.

3. Calculate the relation of primary to secondary turns, E_1 to E_2, and I_1 to I_2 in items 5 and 6, *Order of Work.* Explain.

4. Explain the phenomena observed in item 7, *Order of Work.*

5. In a step-down transformer (E_1 high and E_2 low) why is the primary coil wound with fine wire, and the secondary with heavy wire?

6. Why is the iron core of a transformer laminated?

7. Has the nature of the space between the coils and the outer case, and the construction and size of the outer case anything to do with the power rating of a transformer? Explain.

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EXPERIMENT 25.

Electrical Features of the Transformer and the Transmission of Power.

See Article 69 in the text book, also the *Theory* under Experiment 3 in the Manual.

The object of this experiment is (a) to gain facility in the handling of a commercial transformer; and (b) to study the effect of the voltage value on the transmission of power.

Theory.—The coils of a commercial transformer usually end in a terminal board which is accompanied by a diagram of connections for the various available voltage combinations. While these connections are ordinarily shown on this diagram, it is advisable to know that in connecting the two secondary coils in series, the two coil terminals connected together must be of opposite polarity at the same instant; also in connecting the two secondary coils in parallel, the terminal of one coil must be connected to the terminal of the second coil possessing the same polarity at each instant. (This also applies to the two primary coils.)

In the transmission of a given amount of power (EI) over long distances, the volts (RI) drop and the watts (RI^2) loss in the transmission lines obviously depend on the resistance of the lines and on the current. Hence, for a given size and weight of wire (that is, for a given resistance of the lines) the losses of transmission are less the smaller the current. Since EI represents the power, the transmission losses are, therefore, reduced for a given amount of power transmitted, by using a high voltage (E) and a small current (I). The use of high voltages for transmission is made possible by the transformer, which is arranged to step-up the voltage of the generator at the beginning of a long line, and a second transformer at the end of the line steps down the voltage to a practical working value, thus securing all the advantages of high voltage (that is low current) throughout the length of the transmission wires.

Current Supply.—110 volts Alternating Current.

Apparatus Required.—(1) Two commercial transformers with four coils each (that is, two primary and two secondary coils each), and preferably with a one to one ratio; (2) lamp bank

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to be used as a receiving circuit; (3) three ammeters; and (4) voltmeter.

Order of Work.—1. Connect the primary of one of the transformers to the supply mains (with the two primary and the two secondary coils each in parallel), and connect the secondary to the line. Arrange the second transformer in the same way as regards the connection of its coils, attaching the terminals at the end of the line to its primary and the lamps to its secondary as shown in Fig. 25.

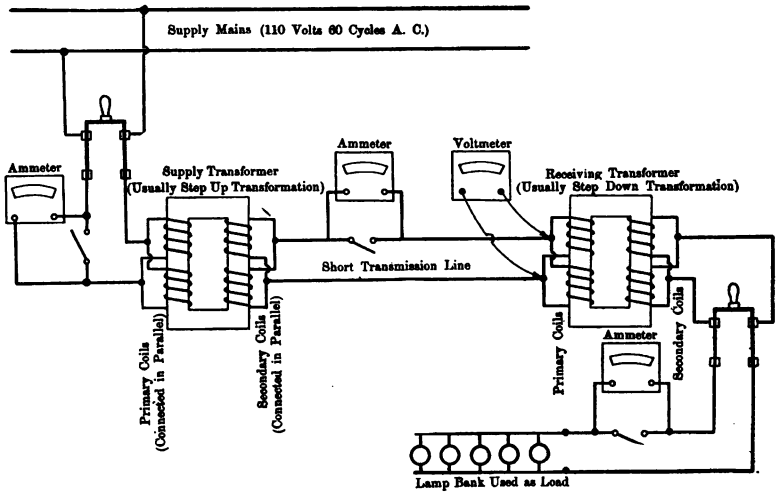

Fig. 25.—Study of the transformer and the transmission of power at different voltages. The short transmission line should be of such length and size as to give a voltage and line loss equal to, say, ten per cent. of the power transmitted in the first case.

2. Observe and record E_1, E_2, I_1 and I_2 in each of the two transformers.

3. Connect the two transformers so that the line voltage is double the value used in items 1 and 2, recording a diagram of the transformer coil connections, and with the same load on the secondary of the receiving transformer, observe and record E_1, E_2, I_1 and I_2 in each transformer.

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Written Report.—1. Calculate the voltage and power loss in the two lines from the observations in items 1 and 2, *Order of Work.*

2. Same, for item 3, *Order of Work.*

3. How do the voltage and power losses compare with the two different line voltages? Explain.

4. Explain, using diagrams, what transformer connections were used to secure the double line voltage in item 3, *Order of Work.*

5. Why must the two terminals, connected together in the case of a two-coil secondary, be opposite in polarity at each instant for the series connection of the two coils? Explain. What would result if these two terminals were of the same polarity at each instant?

6. Why must the terminal of one coil be connected to a terminal of the second coil having the same polarity at each instant in a two-coil secondary for parallel connection of the two coils? Explain. What would result if these two terminals were of opposite polarity at each instant?

7. From the observations in this experiment, explain why high voltage increases the efficiency of transmission of electric power over long distances.

EXPERIMENT 26.

Study of the Induction Motor.

See Fig. 385a, page 497 in the text book.

The object of this experiment is to gain a working knowledge of the construction, and to observe the principles involved in the production of motion in the induction motor.

Theory.—If the field poles of a direct current motor were rotated about the armature, induced electromotive forces would be set up in the armature conductors. If, further, the armature conductors were so connected that the induced electromotive forces thus set up produced a flow of current, the armature wires carrying current would be acted on by the moving magnetic field thus producing a mechanical force or torque tending to cause the armature to rotate.

In the induction motor a rotating magnetic field is produced by alternating current supplied to the stationary field windings

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(called the stator) and this rotating field acts on short circuited conductors thus inducing currents. This, obviously, fulfills the condition for motor action, namely, wires carrying current in a magnetic field. It will be noted that, while the magnetism is rotating, the field windings are themselves stationary, the rotating field effect being made possible by the rapidly changing and reversing alternating current in the stator. The production of this rotating magnetic field by the alternating current is one of the objects of study in this experiment.

Current Supply.—110 volts Direct Current, a low frequency Alternating Current and Alternating Current of the same frequency as the motor assigned.

Apparatus Required.—(1) The field (stator) of a three-phase induction motor with the rotor removed; and (2) a simple iron device corresponding to a compass needle, pivoted in the position of the rotor to indicate the poles of the stator; (3) brake to be used for loading the motor; (4) device for measuring the slip; (5) voltmeter; and (6) ammeter. (If a two-phase induction motor is used, the same instructions apply with obvious modifications.)

Order of Work.—1. Mark or label the three terminals of the stator winding as "1," "2" and "3," in consecutive order, and connect the direct current supply mains through a suitable protective resistance to the terminals 1 and 2, then to 2 and 3, then to 3 and 1 in turn, going through this succession several times. Make a sketch showing the succcessive positions of the pointer as indicating the magnetic field rotation. Observe the number of poles of the stator.

2. Connect the stator to a low frequency supply and observe the action on the pivoted pointer.

3. Make a sketch of the arrangement of several coils in the stator winding as related to each other, that is, showing the angular displacement of the various coils.

4. Make a diagram of the rotor winding showing the details of the end connections of the rotor conductors.

5. Place the rotor in position in its bearings and connect the stator to the rated supply mains (alternating current) allowing the machine to come up to its normal speed. Observe and re-

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cord the speed in revolutions per minute and note the frequency of the circuit used.

6. With normal voltage across the motor terminals, load by means of a brake, and observe and record the torque, current, and slip with increasing load, that is, for zero, ¼, ½, ¾ and full load in turn.

7. Same as item 6, except that ¾ of the normal voltage value is to be used.

Written Report.—1. Explain just how a three-phase current produces a rotating field effect similar to that produced in item 1, *Order of Work.*

2. What determines the number of poles in the stator where the windings are flush with the iron?

3. What is the object in short circuiting the rotor conductors?

4. From the observation of the number of poles in 1 and the frequency in item 5, *Order of Work,* calculate the number of revolutions per minute of the rotating field.

5. What is the numerical difference between the number of revolutions per minute of the rotor as observed in item 5, *Order of Work,* and that of the stator as calculated in item 4, *Written Report?* (Note that the difference between these speeds is the *slip* of the motor.)

6. Plot two curves on the same sheet, using the speed of the rotor (found from the observations of stator magnetism speed and the slip) as abscissas and torque as ordinates, from items 6 and 7, *Order of Work.*

EXPERIMENT 27.

Electrical Features of the Induction Motor.

See the *Theory* under Experiment 26 in the Manual.

The object of this experiment is to observe the conditions which affect the speed and torque of the induction motor.

Theory.—The induction motor may roughly be considered a constant speed machine under constant load conditions. However, as the load increases, the rotor speed falls and the difference between the speed of the rotating field and that of the rotor, name-

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ly the slip (see item 5 under the heading, *Written Report,* in Experiment 26) increases.

Note that the magnetic field rotates at a speed which is proportional to the frequency of the supply current. Thus, if the frequency be reduced to half its original value the magnetic field rotates at half the original speed. The rotor speed depends at no-load on this rotational speed of the magnetic field and, hence, for half frequency the rotor speed (at no-load) is reduced to about half value.

On the other hand, the torque of the motor depends on the magnetic field (which is proportional to the impressed voltage E) and on the rotor current (proportional to the magnetic field and, hence, to the impressed voltage). The torque may, therefore, be said to depend on the square of the impressed voltage (E^2).

Hence, if the frequency be maintained constant and the impressed voltage reduced to half value, the no-load speed of the motor will remain sensibly the same as before (since the magnetic field rotates as before and the torque required at no-load is negligible). If, however, when the motor is loaded, the impressed voltage be reduced to half value, the frequency being maintained constant, the slip will be increased because the available torque is reduced by the reduction of E and this must be made up by the larger rotor currents set up in this case by the higher induced electromotive force in the rotor due to the greater relative motion between rotor and field or, in other words, to the greater slip.

Note, also, that the frequency of the rotor currents is highest when the rotor is at rest, that is, at starting, hence, the reactance of the rotor winding is greatest at this time, and the power factor of the rotor at its lowest. This means that the magnetic field and the rotor currents (the two factors which produce the motion) are at their maximum phase difference when the motor is starting. Since the most advantageous condition for the torque is when the field and rotor currents are in phase with each other (or at their least phase difference) it is obvious that the torque at starting is lower than at any other point of the operation of the motor due to the low power factor.

The principal means for improving the power factor at starting and thus improving the starting torque, is to insert an auxili-

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ary resistance in series with the rotor, which is all cut in at starting and gradually cut out as the rotor comes up to normal speed.

Current Supply.—Three-phase Alternating Current.

Apparatus Required.—(1) Three-phase induction motor with auxiliary resistance arranged in the rotor circuit; (2) brake to be used for loading the motor; (3) device for measuring the slip; (4) ammeter; and (5) voltmeter.

Order of Work.—1. Connect the ammeter in one of the leads of the stator circuit and arrange to drive the motor from supply mains with its normal voltage and frequency.

2. Run the motor unloaded, and observe and record the slip for normal and for ¾ voltage.

3. Starting at zero load with all the auxiliary resistance cut out, and at ¼, ½, ¾, and full load in turn, observe and record the slip and the torque for normal voltage throughout.

4. Same as item 3, for ¾ voltage, as far as the load can be carried.

5. Same as item 3, with ½ the auxiliary resistance cut in.

6. Same as item 3, with all the auxiliary resistance cut in.

7. Tighten the brake, and measure the current in one line and the torque at the pulley at starting, with zero auxiliary resistance in the rotor circuit and using ½ voltage to prevent the flow of an excessive current.

8. Same as item 7, with ½ the auxiliary resistance in the rotor circuit and using ½ voltage.

9. Same as item 7, using all the auxiliary resistance in the rotor circuit and ½ voltage.

10. With all the auxiliary resistance in the rotor circuit, repeat the observations called for in item 7, first, at ½ voltage, and second, at normal voltage.

Written Report.—1. How does the slip compare for the two voltages in item 2, *Order of Work?* Explain.

2. Plot four curves on the same sheet from the observations of items 3, 4, 5, and 6, *Order of Work,* and explain from these curves how the speed and torque vary with the amount of auxiliary resistance in the rotor circuit.

3. What effect on the speed and torque is produced in item 4, *Order of Work,* by the reduced voltage? Explain.

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4. Compare the starting torque for items 7, 8 and 9. How does the auxiliary resistance in the rotor circuit affect the starting torque? Explain.

5. How does the slip at normal, and at ¾ voltage, in item 2, *Order of Work,* compare with the corresponding values in items 3 and 4, *Order of Work,* at full load? Explain.

6. In item 10, how does the starting torque compare at ½, and at normal voltage? Explain.

EXPERIMENT 28.

Study of the Synchronous Motor.

See Fig. 411, page 515 in the text book.

The object of this experient is to secure an idea as to the general operation of the alternator when run as a motor (usually referred to as the synchronous motor).

Theory.—In an alternating current generator (commonly called an alternator) the magnetic field is produced by direct current from a separate source of supply, while the current in the armature conductors is, of course, alternating current. If the alternator is used as a motor, the field winding is supplied by direct current as before, and, as alternating current is supplied to the armature conductors, it will be apparent, after a little study, that the current in a given conductor must reverse in direction in exactly the time taken for the conductor to pass from one pole to an adjacent pole in order that the mechanical force on each conductor may always be in the same direction as the motion.

In other words, the motor must run at the same frequency as the alternator which supplies it with power, and for this reason the motor is called the synchronous motor. When the synchronous motor is started, it must, in general, be brought up to synchronous speed by some outside mechanical means (an auxiliary motor), that is, to the same frequency as the alternator, and the motor must further be connected to the supply mains at that instant when the electromotive force of the armature (called counter electromotive force after the machine is running as a motor) is equal to that of the alternator. This operation is termed synchronizing.

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After being synchronized, the motor continues to run at synchronous (same frequency) speed at all loads, unless, due to an overload its speed be momentarily brought lower than synchronous speed, in which case it stops and must be started as before. Note that the synchronous motor is a constant speed motor and that its speed cannot be adjusted.

Very often the synchronous motor forms a part of what is termed a synchronous converter (or rotary converter), namely, a

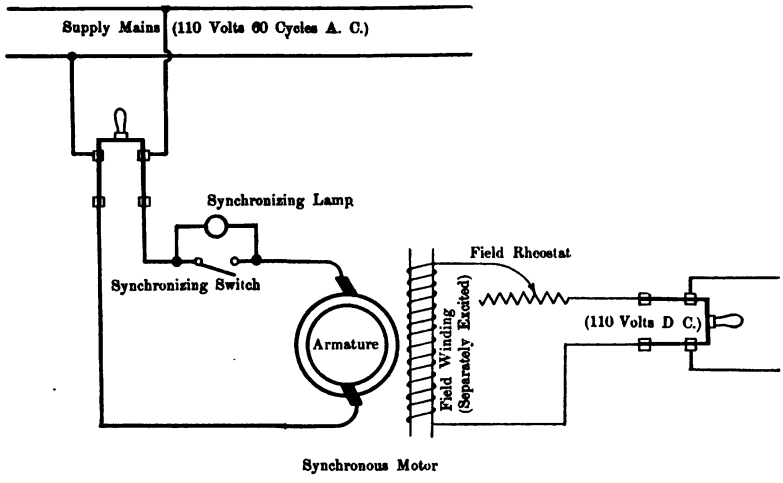

Fig. 26.—Synchronous motor. Note that the main switch is to be thrown in before the synchronizing switch, and the latter not until the conditions for synchronizing are fulfilled. The lamp should be 220 volts, or two 110-volt lamps may be used in series.

machine arranged with collector rings at one end and a commutator at the other end of the armature, each connected to the same armature winding. The common use of the rotary converter is to operate it as a synchronous motor from the collector ring side, for example, in a railway sub-station, and to supply direct current to the railway line from the commutator end of the machine. The rotary converter can, however, be used to run as a direct current motor and supply alternating current, in which case it is sometimes referred to as an inverted rotary converter.

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Current Supply.—110 or 220 volts Alternating Current, and 110 or 220 volts Direct Current (for field excitation).

Apparatus Required.—(1) An alternator to be run as a motor; (2) field rheostat; (3) incandescent lamp to be used for synchronizing; (4) speed indicator; (5) two ammeters; (6) wattmeter; and (7) voltmeter.

Order of Work.—1. Connect the alternator for synchronous motor operation as shown in Fig. 26.

2. Bring up the motor to speed by an auxiliary motor (or by direct current if a rotary converter is used), and adjust the voltage to the value of the supply mains. Determine, by the lamp, when the conditions for synchronizing are realized and connect the motor to the line. Disconnect the driving motor (or the direct current supply to the rotary converter as the case may be).

3. Measure and record the speed of the motor, and observe the number of poles and the frequency of the supply alternator.

4. With the synchronous motor in operation (unloaded) keep the applied electromotive force constant, and measure and record the armature volts and amperes, field amperes and watts delivered to the armature with various field currents, above and below that value giving minimum armature current.

Written Report.—1. Explain in detail the necessary conditions for synchronizing.

2. Compare the speed of the alternator as calculated from the observations in item 3, *Order of Work,* with the observed speed of the motor.

3. Just why must the current in a given synchronous motor conductor reverse each time the conductor passes from a north to an adjacent south pole?

4. In a direct current motor, the field is of course furnished by direct current and although the machine, as a whole, is supplied with direct current, the commutator causes the current in the armature conductors to be alternating. Explain just how the mechanical force in the direct current shunt motor armature conductors is always automatically in the direction of motion.

5. For each of the sets of observations in item 4, *Order of Work,* calculate the apparent watts (*EI*) input to the armature and the power factor (true watts as indicated by the wattmeter

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divided by the apparent watts). Explain any variations in the power factor for the different values of field current.

6. Why is the armature current greater when the field current is above or below that value which gives minimum armature current?

EXPERIMENT 29.

Alternators in Parallel.

See the *Theory* under Experiments 19, 20 and 28 in the Manual.

Theory.—The conditions to be met in the operation of direct current generators in parallel must also be met in the parallel operation of alternators, namely, the polarity of the terminals connected to a given bus bar and the voltage must be the same, and, further, the two machines must have the same frequency.

This means that if one alternator is connected to the bus bars, and a second one is to be connected in parallel with the first, the second machine must be synchronized with the first, like the case described in Experiment 28. Further, if the two machines have the same number of poles, they must obviously run at the same speed to have the same frequency.

The conditions to be met in throwing one alternator in parallel with another may be summarized as follows:

(a) Each machine must have the same terminal voltage.

(b) The two terminals to be connected to the same bus bar must be of the same polarity at each instant, namely, they must be of the same phase.

(c) The machines must have the same frequency.

Current Supply.—110 or 220 volts Direct Current (for field excitation), and the Alternating Current from the alternators assigned.

Apparatus Required.—(1) Two alternators; (2) lamp for synchronizing; (3) speed indicator; (4) lamp bank to be used as a load for the bus bars; (5) three ammeters, one for each machine and one for the total bus bar load; and (6) two voltmeters.

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Order of Work.—1. Arrange the machines and instruments as shown in Fig. 27. Starting up the machines, bring them to normal speed and voltage, and connect one machine to the bus bars (two lengths of wire). Synchronize the second machine with the first and connect it to the bus bars at the proper instant as indicated by the lamp (used for synchronizing).

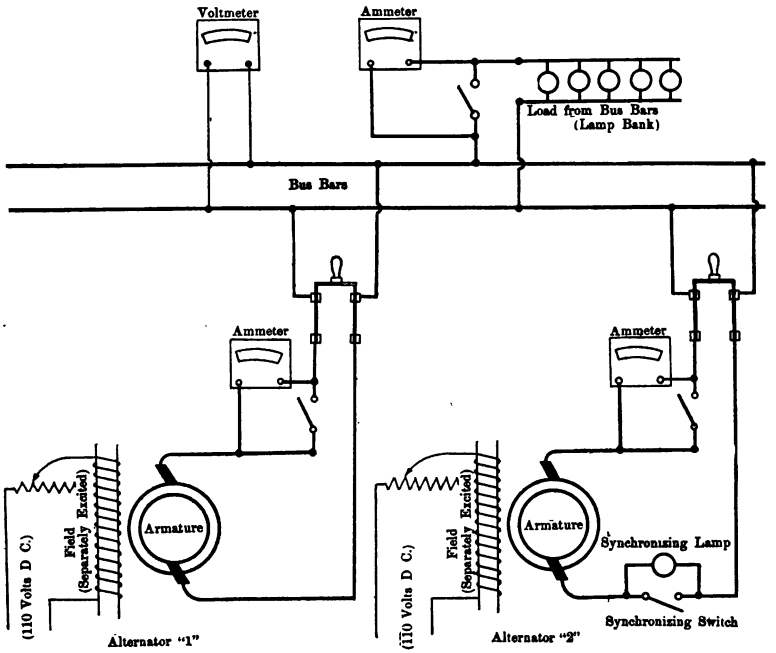

Fig. 27.—Parallel operation of alternators. A voltmeter, not shown in the diagram, is to be available for measuring the voltage of the individual machines.

2. Load the machines from the bus bars until each delivers its full rated load (or some fraction of full load), making needed adjustments of load between the machines with the field rheostats. Observe and record the current delivered by each machine and by the bus bars.

3. Same, for ½ the value of current used in item 2, leaving the field rheostats untouched in the positions as in item 2.

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4. With each machine delivering about ½ its rated load to the bus bars, throw all the load to one of the machines and disconnect the unloaded machine from the bus bars.

5. Start the machines, and load the bus bars until each machine is delivering, say, full load (or some fraction of full load). Raise the field current in one of the machines and lower it in the other, keeping the bus bar voltage constant. Observe and record the effect on (a) the armature currents of the two machines and their arithmetical sum; (b) the total load current from the bus bars; (c) power output (*EI* in the case of lamps); and (d) power delivered by each machine.

Written Report.—1. Explain briefly just why the three conditions for throwing two generators in parallel must be met, as described under the *Theory*.

2. Why are these conditions fulfilled when the synchronizing lamp is dark (or light, depending on which method was used)?

3. Do the machines share the total bus bar load equally when the load is reduced to half value in item 3, *Order of Work*? Explain.

4. Why is it necessary to reduce the load on the one machine to zero before disconnecting it from the bus bars?

5. What would be the effect if one of the machines were disconnected from the bus bars while delivering its share of the total bus bar load?

6. From the observations obtained in item 5, *Order of Work*, state and explain the effect produced on the armature currents of the two machines and their arithmetical sum; the total load current from the bus bars; the power output (total); and the power output from each machine, as the field currents are adjusted.

EXPERIMENT 30.

Study of the Mercury Arc Rectifier.

The object of this experiment is to afford the opportunity for observing the construction and operation of the Mercury Arc Rectifier.

Theory.—The function of this device is to make a uni-directional (one direction) current from alternating current. Its

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principal uses are in connection with arc lighting systems where direct current arc lamps of the Magnetite or Metallic Flame type are used (not operative on alternating current circuits) and where the advantages of distribution of the power by alternating current make it an economy to install this auxiliary piece of apparatus for transforming the alternating to direct current; also where storage batteries are to be charged (with direct current) and alternating current is the only available supply.

The principle of operation depends on the fact that mercury placed in a vacuum bulb with one terminal in contact with the mercury and one terminal above the line of the mercury, permits current to flow through it in one direction only. An ingenious device permits both alternations in each cycle to be used in connection with the rectifier.

Current Supply.—110 or 220 volts Alternating Current.

Apparatus Required.—(1) Mercury arc rectifier; (2) lamp bank to be used as a load; (3) two ammeters; (4) two voltmeters; and (5) a wattmeter.

Order of Work.—1. Connect the rectifier switch to the alternating current supply mains and arrange to load the outfit with the lamps, inserting an ammeter and voltmeter on each side of the rectifier, and a wattmeter on the alternating current side.

2. Start up the rectifier and connect in the alternating current supply. Turn on lamps up to the capacity of the rectifier, and observe and record the current and voltage on each side of the rectifier and the watts on the alternating current side. Note carefully the tilting device for starting the rectifier action.

3. Same, for ¾, ½ and ¼ loads, in turn.

Written Report.—1. Describe briefly the action of the Mercury Arc Rectifier.

2. From the observations in items 2 and 3, *Order of Work,* calculate the efficiency of the rectifier at full load and at ¾, ½ and ¼ loads, also the power factor for each load on the alternating current side and the relation of the alternating voltage to the direct current voltage in each case.

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3. What regular maintenance item must be considered in the operation and up-keep of the rectifier?

4. Although the current can flow in one direction only through the rectifier bulb, the statement was made in the *Theory* that both alternations in each cycle are utilized. Explain how this is possible.

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